Report of the Independent Expert Panel for Mining in the Catchment: Part 2

Coal Mining Impacts in the Special Areas of the Greater Sydney Water Catchment

14 October 2019

Mr Marcus Ray
Deputy Secretary
Planning and Assessment
NSW Department of Planning, Industry and Environment
320 Pitt Street
SYDNEY NSW 2000

Dear Mr Ray

Coal Mining Impacts in the Special Areas of the Greater Sydney Water Catchment

Please find attached the consolidated report of the Independent Expert Panel for Mining in the Greater Sydney Water Catchment (the Panel).

In November 2018, the Panel submitted an Initial Report to the Department in fulfilment of Term of Reference 1. That report was concerned with the two active mines in the Special Areas, Dendrobium and Metropolitan and had a focus on modelling and monitoring used in the assessment and management of mining-induced subsidence effects and impacts on groundwater and surface water. Recommendations were directed at considerations informing mine design and approvals, monitoring and performance. The report set out a number of observations and invited comment as part of the submission and consultation process. It has now been updated and finalised in light of that feedback and constitutes Part 1 of the two-part consolidated report.

Part 2 of the consolidated report addresses Term of Reference 2. It has a focus on the impacts of mining in the Greater Sydney Water Catchment Special Areas on water quantity and swamps, including cumulative impacts, and includes reviewing and updating relevant findings of the 2008 *Southern Coalfield Inquiry (Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield – Strategic Review)*.

I take this opportunity to thank the individuals and organisations that took the time to meet with and make submissions to the Panel over the course of the Review.

Yours sincerely

Emeritus Professor Jim Galvin
Chair, Independent Expert Panel for Mining in the Catchment
14 October 2019

EXECUTIVE SUMMARY

The Independent Expert Panel for Mining in the Catchment was established in late February 2018 to provide expert advice to the (now) Department of Planning, Industry and Environment on the impact of mining activities in the Greater Sydney Water Catchment Special Areas, with a focus on risks to quantity of water.

Four active mines have workings within the Greater Sydney Water Catchment Special Areas. Dendrobium, Russell Vale and Wongawilli mines have workings under the Metropolitan Special Area and Metropolitan Mine has workings under the Woronora Special Area. Only Dendrobium and Metropolitan mines are currently in production.

The Initial Report submitted in November 2018 was concerned with Term of Reference 1. It had a particular focus on modelling and monitoring used in the assessment and management of subsidence-induced effects and impacts on groundwater and surface water at Dendrobium Mine and Metropolitan Mine. Recommendations were directed to informing mine design and approvals, monitoring and performance. The report set out a number of observations and invited comment as part of the submission and consultation process. It has now been updated and finalised in light of that feedback and constitutes Part 1 of the two-part consolidated report.

This Part 2 Report addresses Term of Reference 2, which has a focus on the impacts of mining in the Greater Sydney Water Catchment Special Areas on water quantity and swamps, including cumulative impacts, and a requirement to review and update relevant findings of the 2008 Southern Coalfield Inquiry (SCI). The Panel's work has been constrained in some aspects because Russell Vale and Wongawilli mines are on care and maintenance. However, the Panel considers that this is very unlikely to impact its principal findings.

The 2008 SCI Report represented a landmark development of the then-current state of knowledge of the impacts of underground coal mining on natural features. This informed the regulatory framework and best-practice approach to the assessment and management of risk and subsidence-induced impacts, effects and consequences.

The current development consent for Metropolitan Mine was issued in 2009 and it is the first of the four active mines in the Special Areas to be approved under the current legislative framework, which required the (now) Independent Planning Commission to give consideration at the time to the SCI findings. The Dendrobium Mine was approved almost two decades ago, with its development consent being modified in 2008, 2015 and 2018 and due to expire in 2030. Its environmental performance measures, complemented by a provision to offset impacts to swamps, provide considerable scope for maximising mining dimensions. Russell Vale Mine does not hold a current approval to undertake total extraction operations and the approval for Wongawilli Mine expires at the end of 2020.

Mining predates the declaration of the Special Areas. The Panel has had regard to the fact that mining activities are being undertaken in a complex and relatively unique combination of geotechnical, hydrogeological and environmental conditions, with an incomplete design knowledge base that is still evolving and which may never be complete, and with high potential consequences if mine design is inappropriate for the circumstances.

Only high level findings and recommendations are presented in this Executive Summary. A complete reading of the detail contained in the chapters of this Part 2 Report and those in the Part 1 Report is required to understand the full range of the Panel's findings and recommendations across the course of the Review.

Since the SCI Report

- Height of fracturing leading to groundwater depressurisation has emerged as a critical issue. It has very significant implications for the permanent diversion of catchment water into mine workings, including on a regional basis, and for the reliability of predictions of impacts and consequences for groundwater and surface water.
- There is increasing recognition of the potential for geological discontinuities to act as or become conduits for groundwater flow.
- It is now established that longwall mining directly under swamps in the Southern Coalfield can result in significant changes to swamp hydrology and redirection of surface runoff, which the Panel considers are very likely irreversible.
- Despite substantial research, there has been little advance in the reliable prediction of non-conventional subsidence effects and impacts. There are considerable disparities between predicted and measured valley closures, reflecting the complex and site-specific nature of ground responses to mining in Southern Coalfield conditions. Predictions continue to be based on a worst-case approach.
- Likelihood relationships for the Southern Coalfield have been derived between predicted total valley closure and the proportion of fractured rockbars that control pool water levels on watercourses. While a helpful advance, limitations are still associated with this approach and the prediction of mining impacts and consequences for watercourses remains an incomplete process.
- The understanding of the contribution that swamps make to baseflows continues to be limited, with no accurate water balance being available for any swamp in the Southern Coalfield and no strong evidence to date of consequences of swamp impacts on catchment-scale water supplies.
- Despite decades of monitoring, mining-induced changes to upland swamp vegetation communities are still not able to be clearly differentiated from natural changes.
- There is very limited, if any, scope for remediating fracture networks beneath swamps. Therefore, in circumstances where it is difficult, if not impossible, to design a viable mining layout that avoids impacting swamps and mining is to proceed, there is little option other than to consider offsets as compensation for the consequences of negative environmental impacts on swamps.

Current water losses

- There is an increasing body of evidence that mining in the Metropolitan Special Area has resulted and continues to result in losses of water from the Greater Sydney water supply system. The losses include surface water diversions into the mines, leakage from reservoirs into the mines and loss of baseflow in watercourses due to groundwater depressurisation. Presenting a definitive recent loss rate for the Metropolitan Special Area is complex because the available estimates correspond to different time periods and/or catchment areas, and no estimates are available for most historical mines.
- Available estimates show that the upper limit of recent loss rate totalled over the Dendrobium, Wongawilli and Russell Vale mines is an average of 8 ML/day and for the Dendrobium Mine alone is less than 5 ML/day. Loss rates from both Dendrobium and Metropolitan mines are expected to increase as the area of excavated coal seams increase. Loss rates at Dendrobium Mine vary over time depending on rainfall.
- These losses are low compared to other components of Greater Sydney's supply and demand. For example, 8 ML/day compares to the Sydney Desalination Plant capacity of approximately 250 ML/day and estimated leaks from the Greater Sydney supply infrastructure of approximately 130 ML/day.

- Losses of water from the Woronora Special Area due to mining impacts associated with Metropolitan Mine are negligible, with a water make between 2009 and 2017 that has averaged at 0.09 ML/day and, with the exception of May 2011, a 20 day average water make below 0.5 ML/day.
- The higher rate of loss associated with Dendrobium Mine is due to a mine geometry that leads to a greater height of fracturing, greater depressurisation of groundwater throughout the vertical profile from the mined coal seam to the surface and loss of surface water through fractures that connect the mined coal seam to the surface.
- The qualitative nature of flow loss and watercourse impact performance measures applied to Dendrobium Mine has led to differing opinions about whether performance measures have been met, particularly whether the frequency and spatial extent of impacts observed can be considered minor. This arises partly due to past lack of knowledge about of height of fracturing and the potential for regional depressurisation and partly due to the limitations of employing qualitative performance criteria.
- There are short-term and long-term environmental benefits associated with preventing the height of free drainage in the Special Areas from intersecting the surface either directly or indirectly by interaction with surface fracture networks. This does not eliminate the risk of surface water and swamps continuing to be impacted by conventional and non-conventional subsidence but it may reduce the scale of these impacts.

Current water quality

- Although surface fracturing elevates metal loads in watercourses, there is no evidence that mining in the Special Areas is currently compromising the ability of WaterNSW to meet raw water supply agreement standards.

Cumulative water losses and quality from future and historic mining

- Considerable progress has been made since the SCI in quantifying the impacts of the Metropolitan and Dendrobium mines using 3D groundwater models. While there is a need to continue to improve the model accuracy and to improve reporting of uncertainty, 3D groundwater modelling along with supporting monitoring remains the best practicable approach to estimating water losses from ongoing and proposed mining operations.
- Building a 3D model is not a realistic option for historic mining areas due to the complexities of the physical system, and the high costs of developing models and the necessary supporting monitoring. Due to the absence of alternative applicable modelling approaches, expert judgement based on general knowledge of how mines of different geometries interact with hydrogeology is likely to provide the best practicable estimates of losses from historical mines.
- In order to assess long-term cumulative impacts of mining on water quantity and quality in the Greater Sydney Water Catchment, there is a need to establish the state of rehabilitation and closure of mines in and adjacent to the catchment. The issue is complicated by factors such as:
    - the lack of historical records and monitoring
    - the variety of mining systems and the interaction and overlap of mine workings within and between mines
    - the lack of detailed mine closure planning in the past
    - topographical influences.
- As the groundwater table recovers following the cessation of mining, the rising groundwater will inundate subsurface voids and fracture networks and leach metals. The potential for these storages to overflow in the long term to the surface via fractures needs increased attention in mining proposals, especially in the Special Areas where the

cumulative impacts could have serious negative consequences for reservoir water quality.

- Where mine entrances (or other natural or mining-induced flow conduits) emerge outside the Special Areas at an elevation below the groundwater table and cannot be effectively and safely sealed, a perpetual water loss is likely. Potentially, water flowing from these conduits will require treatment in perpetuity before discharge to waterways or being put to beneficial use.

Quantifying significance of water losses for Greater Sydney's water supply system

- The significance of any water loss from the Special Areas depends on whether, when and to what extent the loss impacts on long-term predictions of Greater Sydney's reliable water supply and any compensatory measures required. WaterNSW presented to the Panel a proposed approach towards assigning a level of significance to thresholds of cumulative water loss. The development and refinement of this approach has the potential to provide a more objective basis for proposing acceptable cumulative loss thresholds and a basis for seeking consensus on thresholds both for cumulative and mine-specific losses among relevant agencies.

Offsets

- Options identified for offsetting water loss from the Special Areas include:
  - 'purchasing' the water lost from the catchment that can be attributed to mining operations, the financial offset could be used to fund make-up water sources, such as through the operation of desalination plants and borefields, or
  - treating the water pumped from the mine to a standard that enables it to supplement water that would otherwise be drawn from the Greater Sydney Water Catchment.

  Neither of these options address long term impacts on water quantity and quality post-mine closure. Provision needs to be made for water take to fill the mine post closure and arrangements that may be required in perpetuity if the water table cannot be re-established.

Mine Rehabilitation and Closure Planning

- Submissions to the Panel gave limited consideration to the long term post-rehabilitation and mine closure impacts on water supply from the Special Areas.

Regulatory Process

- The concept of Reverse Onus of Proof as proposed in the SCI Report has not proven workable.
- In the Part 1 Report, the Panel endorsed government's approach of approving longwall panels at Dendrobium and Metropolitan mines on an incremental basis. The Panel appreciates industry concerns about the negative implications that this approach can have for operational continuity, investment certainty and long-term project viability. The situation reflects that longwall mines in the Special Areas are operating in complex and relatively unique conditions with an incomplete design knowledge base and, consequently, there is a history of significant variation between some important predicted and measured impacts. Due diligence in risk management currently necessitates incremental approvals and external expert review.
- In assessing complex mining applications, the government currently relies on initiatives such as approval conditions for Dendrobium Mine and Metropolitan Mine that require the mines to appoint an expert panel to the satisfaction of the Secretary, on the appointment of its own expert panels on an *ad hoc* basis, and the commissioning of consultants reports. The Panel identified a need in its Part 1 Report for government to have a more

sustainable mechanism for accessing objective expert advice when assessing mining applications and performance outcomes. Community has responded with concerns about industry exposure and potential conflicts of interest of many experts, and industry has expressed concerns about transparency and timeliness for advice.

- Since the SCI, there has been a progressive move away from specifying performance measures in qualified terms, and towards more quantifiable terms. There are still opportunities for government to improve the effectiveness of performance measures, especially for watercourses and swamps, by specifying them in terms that are less ambiguous and more quantifiable and measurable.

Recommendations

- The concept of Reverse Onus of Proof as proposed in the SCI Report should be discarded.
- Remediation should not be relied upon for features, including watercourses and swamps, that are highly significant or of special significance (as per the guidance provided by the Planning Assessment Commission Panels for the Metropolitan Coal Project and the Bulli Seam Operations Project).
- Impact assessments associated with proposals for mining in the Special Areas need to include detailed consideration of rehabilitation and mine closure planning.
- Government needs to establish a sustainable mechanism for accessing objective and timely expert advice when assessing mining applications and performance outcomes and this mechanism needs to be supported by probity guidelines that have regard to experts having worked in the mining industry in order to gain their expertise.
- Government should seek opportunities to improve the effectiveness of performance measures, especially for watercourses and swamps, by specifying them in unambiguous, quantifiable and measurable terms.
- All future mine approvals in the Special Areas should include performance measures related to measured changes in groundwater pressure and/or pressure gradients where these have the potential to impact on surface water diversions or losses.
- WaterNSW should continue its program of work towards determining the significance for the Greater Sydney water supply of different thresholds of surface water loss due to mining.
- An inter-agency working group should be set up with the task of identifying acceptable levels of surface water loss due to mining.
- A study should be undertaken to better understand and quantify the potential impacts of historic and current mining for long-term cumulative impacts on water quantity and quality in the Greater Sydney Water Catchment Special Areas, for the purpose of properly informing mine design, offsets, mine rehabilitation and closure planning, planning assessments and rehabilitation bonds.
- Research be undertaken into:
    - quantifying the height of complete drainage above mining operations in the Sydney Water catchment
    - the reliability of alternative geomechanical modelling of rock fracturing and fluid flow for informing the calibration of groundwater models at mine sites in the catchment.
    - establishing the potential for regional movement on bedding planes and the potential consequences that this may have, especially in the vicinity of water storages.

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1 INTRODUCTION

In November 2017 the NSW Government established the Independent Expert Panel for Mining in the Catchment (the Panel) to provide expert advice to the (now) Department of Planning, Industry and Environment (the Department) on the impact of mining activities in the Greater Sydney Water Catchment Special Areas (the Special Areas), with a particular focus on the risks to the quantity of water in the Catchment.

Advice was to include, but not be confined to, risks to the total water quantity and holding capacity of surface and groundwater systems, including swamps and reservoirs, and the types and reliabilities of methodologies used to predict, monitor, assess and report on mining effects, impacts and consequences. Terms of Reference for the Panel are at Appendix 1.

In November 2018 the Panel submitted its Initial Report that was concerned with Term of Reference 1. The report had a particular focus on modelling and monitoring used in the assessment and management of subsidence-induced effects and impacts on groundwater and surface water at Dendrobium and Metropolitan mines. Recommendations were directed to informing mine design and approvals, monitoring and performance. The report set out a number of observations and invited comment as part of the submission and consultation process. It has now been updated and finalised in light of that feedback and constitutes Part 1 of the two-part consolidated report.

This Part 2 report addresses Term of Reference 2, which has a focus on the impacts of mining in the Greater Sydney Water Catchment Special Areas on water quantity and swamps, including cumulative impacts. This includes reviewing and updating relevant findings of the 2008 Southern Coalfield Inquiry report, *Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield – Strategic Review* (the SCI Report) (Hebblewhite et al., 2008).

The SCI Report was published in July 2008. It represented a landmark development of the (then) current state of knowledge of the impacts of underground coal mining on natural features and informed the regulatory framework and best-practice approach to the assessment and management of risk and subsidence induced impacts, effects and consequences.

Soon thereafter, the (then) Planning Assessment Commission (PAC) assessed the Metropolitan Coal Project (MCP), producing its report in May 2009 (DoP, 2009). The PAC's Terms of Reference required it to take into consideration the recommendations of the SCI, which the PAC interpreted as including a requirement to provide an assessment of how they might be applied to a substantive mining proposal and to suggest any variations or enhancements that may facilitate application to future proposals. Some 14 months later, the PAC published the report of a second substantive coal mine assessment in the Southern Coalfield, which was in relation to the Bulli Seam Operations (BSO) Project (PAC, 2010). The Terms of Reference for that assessment also included a requirement to take into consideration the recommendations of the SCI.

Both the MCP and the BSO Project received conditional approval. Subsequently, to the end of June 2019, no assessments of other substantive new coal mining projects (excluding modifications) in the Southern Coalfield have been finalised. In 2015, the PAC reviewed the Russell Vale Colliery Underground Expansion Project, concluding that the project required more work and assessment before a determination could be made. An assessment of the Hume Coal Project is in progress, while the Tahmoor South Coal Project and the Dendrobium Mine Extension Project were both submitted for assessment during the preparation of this report.[1,2] The Tahmoor South Coal Project is not within the Special Areas. Hence, the SCI Report and the application of its findings have already been scrutinised twice by independent (PAC) panels, albeit some time ago. The Panel has had particular regard to the findings documented in the PAC reports for the MCP and BSO projects.

1.1 BACKGROUND

The coal seams of the Southern Coalfield underlie the Upper Nepean and Woronora catchments which supply water to the Greater Sydney region. The major dams, reservoirs and canals used for water supply are surrounded by Special Areas, managed by WaterNSW, within which access and certain types of activities are restricted to protect water quality and maintain ecological integrity (Figure 1A).

There are four mines in the Special Areas. Dendrobium, Russell Vale and Wongawilli mines are located in the Metropolitan Special Area and Metropolitan Mine in the Woronora Special Area. Mining at Russell Vale and Metropolitan mines dates back to the mid-1880s. Currently, only Dendrobium and Metropolitan mines are in production. The characteristics and locations of the four mines are presented in Table 1 and Figure 1.[3]

The five dams in the Metropolitan and Woronora Special Areas (Avon, Nepean, Cordeaux, Cataract and Woronora) were built in the early to mid-1900's to capitalise on the region's high and reliable rainfall. They currently supply an average of 28% of the water to Greater Sydney (WaterNSW, 2019a) as well as providing environmental flows to maintain downstream river health.

[1] Wollongong Coal submitted a revised expansion project (Revised Preferred Project Report and Response to Second PAC Review) that was put on public display in August 2019. This revised plan no longer includes longwall mining.
[2] The three projects have not been considered as they remain under assessment.
[3] The Southern Coalfield is known for the production of hard coking coal used in steel production. Thermal coal is also produced, generally as a by-product and in much smaller quantities. Mining in the Southern Coalfield began in the 1800s, prior to the establishment of the Special Areas. A history of the four mines is at Appendix 2 of the Part 1 Report.

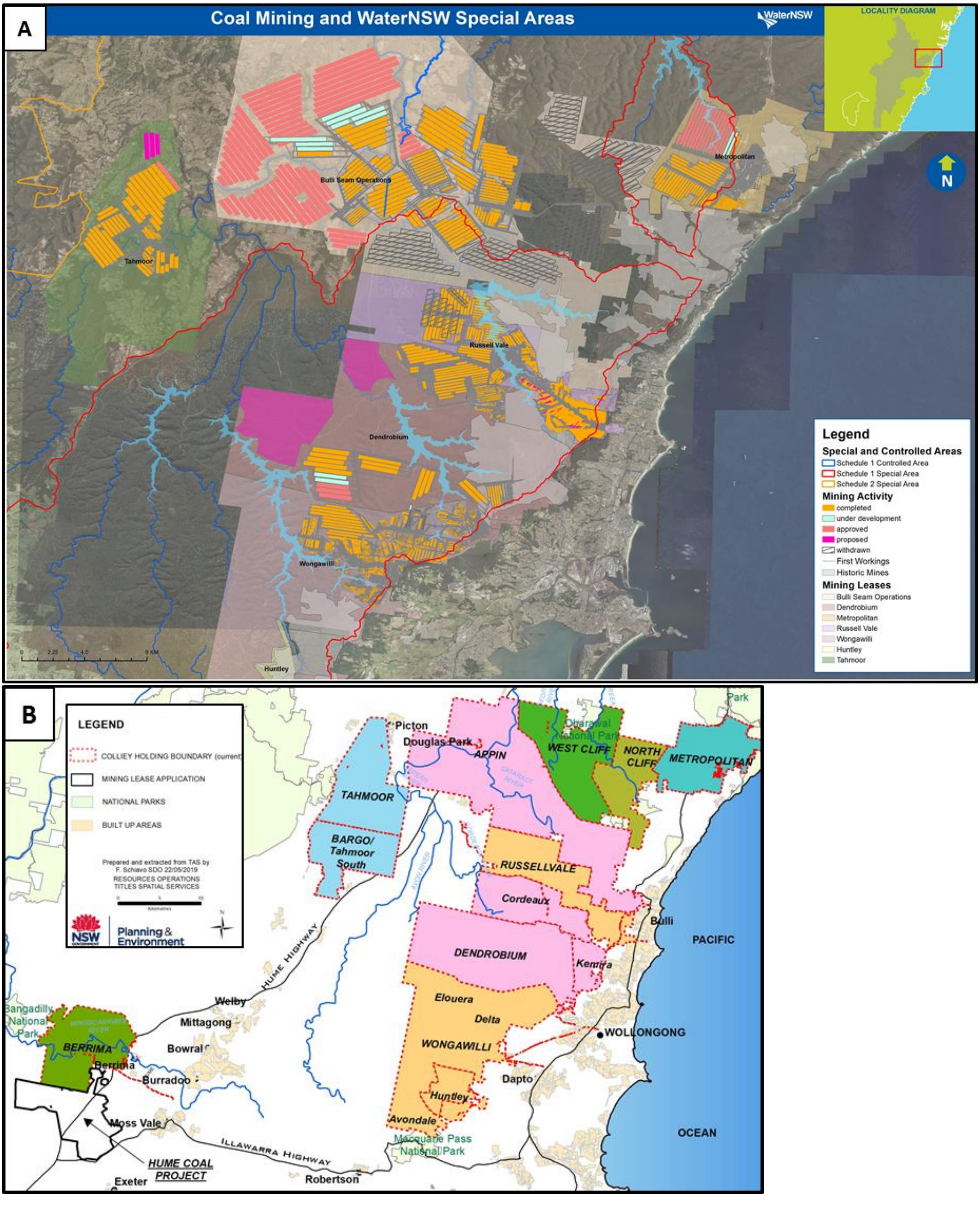

Figure 1: A) Historic and proposed coal mining in the Special Areas and B) current mining leases in the Southern Coalfield

Source: A) Submission No.2, WaterNSW, B) DPE (2019)

Table 1: Details and status of current coal mines in the Metropolitan and Woronora Special Areas

Notes		Dendrobium Mine	Metropolitan Mine	Russell Vale Mine	Wongawilli Mine
Current Seam		Wongawilli	Bulli	Bulli, Wongawilli[13]	Wongawilli[14]
Catchment		Avon (Area 3B and proposed 5) Cordeaux (Areas 2, 3A and proposed 6)	Woronora	Cataract	Avon
Special Area		Metropolitan	Woronora	Metropolitan	Metropolitan
Mining Leases		CCL 768 (18,560 ha) ML 1510 (44.03 ha) ML 1566 (5.26 ha)	CCL 703 (5,195 ha) ML 1610 (543.3 ha) CL 379 (59.82 ha) ML 1702 (386.4 ha)	CCL 745 (6,420ha) ML 1575 (544.4 ha) MPL 271 (8.75ha)	CCL 766 (514 ha) ML 1565 (3,177 ha) ML 1596 (11,074 ha)
Longwall (LW) dimensions (m)	Void width	245 - 305	125 - 163	140	84 - 171
	Length	1,590 - 2,591	1,158 - 3,085[1]	523 - 844[15]	358 - 1,785
	Max height	3.4 - 4.5[2]	2.8 - 3.3[3]	3 - 3.5	2.8 - 4.0[16]
	Depth of cover	138 - 409[4] (Area 3B mean 364)	390 - 540[5] (mean 459)[6]	267 - 279	180 - 360
Run-of-mine coal per year (million tonnes)	Approved	5.2[7]	3.2[8]	1[17]	2[18]
	Actual	4.57 (2017), 4.42 (2016)[9]	1.37 (2017), 2.24 (2016)[10]	N/A	0.2[19]
Current Groundwater (GW) entitlements	Water Source Entitlement (ML/year)	Sydney Basin Nepean: 3,962 Sydney Basin South:75[11]	Sydney Basin Central: 182.5 South. Sydney Rivers: 130[12]	Sydney Basin Nepean: 515[20]	Sydney Basin Nepean: 1500[21]
Status CM= care & maintenance		Active LW 15	Active LW 304	CM since 2015	CM April 2019
Proposals		Extension Project (Areas 5 and 6)		Underground Expansion Project	

1. MSEC (2012, 2013, 2014, 2015, 2016b, 2017)
2. HydroSimulations (2015)
3. Max Extraction Height LW 12-17: 3.3 m
4. HydroSimulations (2015)
5. Minimum 390 m for LW 10-11; Maximum 540 m for LW 23A and 302
6. Peabody (2018b)
7. Dendrobium development Consent
8. Metropolitan Mine development Consent
9. South32 (2017b)
10. Peabody (2018a)
11. Water Access Licences WAL37465 and WAL36473, HydroSimulations (2016)
12. Water Access Licence WAL25410 and WAL36475 (through Bore Licence 10BL603595) (Peabody, 2019a)
13. Mine in care and maintenance since 2015 and historically mining also in the Balgownie seam
14. Mine in care and maintenance since April 2019 and historically mining also in the Bulli seam
15 These dimensions are for LW 4 (2012) and LW 5 (2014) under Project Approval MP 10_0046 (2011) by Gujarat NRE (Wollongong Coal, 2014)
16. Dimensions for LWs under Project Approval 09_0161 (2011) including Nebo Area LWs N2 and N4 by Gujarat NRE (Gujarat NRE FCGL, 2012) (SCT Operations, 2017) (Wollongong Coal, 2019b)
17. (Unwelt Australia, 2016)
18. (Umwelt Australia, 2016)
19. 199,839 tonnes from July 2017-June 2018 (Wollongong Coal, 2019b)
20. WAL36488
21. WAL36487

1.2 PROCESS FOR THE PANEL

1.2.1 Panel Composition

The Panel was comprised of technical experts in the areas of mining, subsidence, groundwater, surface water and swamps. Members are Emeritus Professor Jim Galvin (Chair and mining and subsidence expert), Professor Neil McIntyre (surface water), Mr Robert Williams (groundwater), Dr Ann Young (swamps), Professor Ismet Canbulat (subsidence) and Dr Chris Armstrong (Deputy Chief Scientist & Engineer). Professor Canbulat joined the Panel in January 2019.

Secretariat support for the Panel was provided by the Office of the NSW Chief Scientist & Engineer.

1.2.2 Meetings and site visits

Minutes of meetings are available on the website of the NSW Chief Scientist & Engineer.

The Panel conducted four site visits over the course of the Review (Appendix 2). These site visits were to swamps and watercourses above past, current and proposed mine operations at the Dendrobium and Metropolitan mines.

1.2.3 Consultations

The Panel conducted consultations in Sydney (31 January 2019), Picton (12 February 2019) and Wollongong (28 February 2019). This included consultations with representatives from NSW Government agencies, local government Councils, mining companies, community consultative committees and community organisations. Attendees are listed in Appendix 2.

1.2.4 Submissions

The Panel received 81 submissions over the course of the entire Review (Appendix 2). In addition, it received 382 standard form emails recommending an immediate moratorium on further coal mining in Sydney's drinking water catchment and copies of 43 letters addressed to the Premier of NSW expressing concerns about coal mining in the catchment and calling for a ban on all mining in the Special Areas.

Submissions to the Panel are available on the website of the NSW Chief Scientist & Engineer.

1.2.5 Referrals under Term of Reference 3

Under Term of Reference 3, the Panel was requested to provide advice to the Department on mining activities in the Special Areas. The Panel prepared advices on the following referrals:

- Dendrobium Mine Subsidence Management Plan for Longwall (LW) 16
- Dendrobium Mine Subsidence Management Plan for LW 17
- Metropolitan Mine LW 303 Extraction Plan
- Metropolitan Mine application to amend the first workings layout for LWs 304 to 306
- Metropolitan Mine LW 303 Extraction Plan – request for further extraction
- Metropolitan Mine LW 304 Extraction Plan

As a result of its deliberations on matters arising from the Initial Report and from referrals under Term of Reference 3, the Panel also provided separate advice to the Department regarding emerging knowledge related to the potential impacts of geological lineaments on subsidence, groundwater, surface water and swamps.

1.3 KEY THEMES FROM CONSULTATIONS AND SUBMISSIONS

Stakeholders raised a range of topics in submissions and consultations, giving a spectrum of perspectives on the issues that are substantively dealt with in relevant parts of this report.

The most critical themes related to environmental impacts, security of water supplies and the adequacy and certainty of the regulatory regime. The latter included efficacy of performance measures and Trigger Action Response Plans (TARPs)[4] used for tracking performance, rehabilitation and use of offsets, incremental approvals, and economic implications. Strengthened monitoring, accessible data collections, use of independent experts and transparent decision-making also featured.

Some submissions canvassed issues outside the scope of the Panel's Terms of Reference, including mining outside the Special Areas and damage to heritage sites.

Community environmental group submissions, supported by an email campaign, called for an immediate moratorium on further coal mining in the Greater Sydney Water Catchment Special Areas. Core themes were water loss in the context of increasing supply and demand (including population growth, drought and climate change) and irreversible damage to a protected (intended to be pristine) area and groundwater dependent ecosystems including swamps. Many contrasted the current arrangements where mining-related activities occur in the Special Areas but members of the public are faced with a potential fine of $44,000 if they enter the Special Areas.

There were a number of comments on water security and the volume of water loss. This centred on the (un)acceptability of the water loss and cumulative impacts of water loss on the supply of drinking water and on the environment.

1.4 STRUCTURE OF THIS REPORT

- Chapter 2 provides an update of knowledge of subsidence effects and impacts
- Chapter 3 provides an update of knowledge of mining impacts on groundwater and surface water and consequences for water supply
- Chapter 4 provides an update of knowledge of mining impacts and consequences on swamps
- Chapter 5 discusses additional matters arising out of submissions, the Panel's Term of Reference 2 to review and update relevant findings of the SCI, and the experiences of the PAC in applying the findings of the SCI.
- Chapter 6 concludes the report, providing a summary of major conclusions and recommendations.

[4] A Trigger Action Response Plan (TARP) is a preventative and adaptive management tool commonly used in the mining industry, particularly for managing mine safety operations. The plan identifies a hierarchy of threshold conditions (or 'triggers'), actions to be taken, and accountabilities for these actions, when thresholds are reached (triggered).

2 SUBSIDENCE EFFECTS, IMPACTS AND CONSEQUENCES ON WATER SUPPLY

The term *subsidence* in this report refers to all mining-induced deformation of the overburden (or subsurface) and the surface. The manner in which subsidence develops over mine workings and how it can affect natural and built features has been described in some detail in the SCI Report and the Panel's Part 1 Report.

The focus of this chapter is on providing a summary update of changes since 2008 relevant to assessing mining impacts on groundwater and surface water, including swamps.

2.1 FOUNDATION SOUTHERN COALFIELD INQUIRY FINDINGS

2.1.1 Definitions

The SCI drew distinctions between subsidence effects, subsidence impacts and subsidence consequences. Subsequently, these distinctions have been slightly refined and generally adopted by the minerals industry and regulators in NSW. The Panel concludes from documentation and submissions that the distinctions as summarised below are working well and should continue to be embedded in future mining assessment processes:

- **Effect** - the nature of mining-induced deformation of the ground mass
- **Impact** - any physical change caused by subsidence effects to the fabric of the ground, the ground surface, or to a natural or constructed structure
- **Consequence** - any change caused by a subsidence impact to the amenity, function or risk profile of a natural or constructed feature. Some consequences may give rise to secondary consequences.

The SCI also distinguished between what it called 'conventional' and 'non-conventional' subsidence. This was on the basis that the conventional or general model of surface subsidence is based on the presence of straightforward and uniform site conditions, including:

- the surface topography is relatively flat
- the surrounding rock mass is relatively uniform and free of major geological disturbances or dissimilarities
- the surrounding rock mass does not contain any extremely strong or extremely weak strata.

The SCI discussed a range of situations where these conditions are not met, including when the surface topography is steep and/or incised by valley and gorges as in the case of the Southern Coalfield. It noted that in these circumstances, surface subsidence effects vary from those that would be predicted using the conventional model and that such subsidence effects are generally known as non-conventional although this is somewhat of a misnomer. The SCI acknowledged that the subsidence effects remain conventional and what has varied are the site conditions in which they take place. However, for the sake of simplicity, the SCI applied what it considered to be the general terminology.

The Panel has continued to adopt the terminology of conventional and non-conventional subsidence for the sake of consistency. However, it is apparent that the term 'non-conventional' does not have the same level of acceptance amongst practitioners as the definitions of subsidence effects, impacts and consequences and can incorrectly imply to the layperson that subsidence is outside the range of normal or expected behaviour.

2.1.2 Performance measures (standards) and indicators

Mining consents in NSW prior and subsequent to the SCI have been based on subsidence performance measures of 'negligible' and 'minor', where negligible is defined as 'small and unimportant, such as to be not worth considering' and minor as 'not very large, important or serious'. No classification system applies to impacts that are greater than minor.

The SCI concluded that subsidence impact assessments in the Southern Coalfield had generally focused too much on the prediction of subsidence effects, rather than the accurate prediction of subsidence impacts and their consequences. While there had been substantial improvements in the industry's ability to predict impact and consequence in recent years, these predictions had generally been qualitative in nature (e.g. 'moderate cracking', 'a possibility that some pools will drain'). Consequently, it had been difficult for agencies to establish whether impacts were greater or less than predicted. The SCI reported that the challenge for the mining industry and its consultants over the next few years would be to move to a new generation of predictive capacity which is essentially quantitative in nature.

The SCI went on to state that environmental impact assessment, performed at the application stage for project approval under Part 3A of the *Environmental Planning and Assessment Act 1979* (EP&A Act), should be the primary tool used to set the envelope of all acceptable environmental impacts for mining projects. Ultimately it was the Government's responsibility to determine what environmental impacts are acceptable. This envelope of acceptability should be expressed in clear conditions of approval which establish measurable performance standards against which environmental outcomes can be quantified.

It stated that once the expected outcomes are defined and an underground mining project has project approval under Part 3A (now Part 4), the essential role of the Subsidence Management Plan (SMP, since superseded by the Extraction Plan (EP)) should be to ensure that the risk of impacts remains within that which was assessed and approved.[5] The EP should be a management document, that is, plans should be prepared to demonstrate how the required outcomes will be achieved, what monitoring will occur and how deviations and contingencies will be addressed.

The MCP PAC reported that where the predicted subsidence impacts could lead to unacceptable environmental consequences for significant natural features, it had, wherever possible, adopted a strategy of specifying the outcomes to be achieved for the feature rather than prescribing limits for subsidence effects and/or impacts, or setting arbitrary mining setbacks. The PAC considered that it should be up to the Proponent to satisfy the Consent authority and the regulators that the proposed strategies will achieve the required outcomes. However, such an approach will only work if failing to achieve the outcomes carries unattractive consequences for the Proponent (PAC, 2009).

SMPs and EPs effectively constitute a Proponent's strategies for achieving Performance Measures (also referred to as Performance Standards) embedded in consent conditions. Monitoring is an essential element of these strategies, not only for verifying compliance but even more importantly, for providing early warning that actual outcomes may be deviating adversely from predictions. TARPs find extensive use in the Australian mining industry for this purpose. They are based on monitoring select responses to mining, referred to as

[5] Mining in the catchment predated the declaration of Special Areas and mining approvals were historically managed under mining and not environmental legislation. The introduction in 2005 of the *EP&A Act* removed previous exemptions for coal mines from the requirement to obtain development consent under that Act; mines having until 2010 to obtain approval. The EP&A *Amendment (Part 3A Repeal) Act 2011* established a new assessment pathway under Part 4 (replacing Part 3A) for State Significant Developments (SSDs) including mines. Agency responsibilities under multiple regulatory instruments have been integrated into the planning process, including those under the *Mining Act 1992* (which superseded the *Coal Mining Act 1973* and *the Mining Act 1906*). Consistent with this, a consolidated EP (including subsidence management) is now required as a condition of Consent (under the *EP&A Act*), replacing SMPs previously required as part of mining leases (under the *Mining Act 1992*).

‘performance indicators’ that trigger interventions if performance indicators exceed predetermined threshold or trigger levels.[6]

It is apparent from submissions to the Panel that some stakeholders confuse a performance indicator with a performance measure. A performance indicator is a point of reference to assist in avoiding a breach of a performance measure. The proponent has the flexibility to select performance indicators and the trigger levels assigned to them. The Proponent does not have the latitude to determine or exceed a performance measure.

2.1.3 Integration between studies and disciplines

The SCI identified that one of the weaknesses in the system of impact assessment and subsidence management appeared to be the lack of integration between the various scientific studies carried out by a large number of disciplines. These included for example, subsidence predictions, water quality and flows, landscape, terrestrial flora and fauna, aquatic flora and fauna. It reported that poor integration of the assessment of subsidence *effects* and *impacts* (within a subsidence impact assessment) with the environmental *consequences* of those impacts had led to situations where there may be an incomplete overall understanding and appreciation by both the community and government agencies of the predicted impacts and consequences of a mining activity.

The only two substantive mining proposals in the Southern Coalfield to be determined since the SCI (being the MCP in 2009 and the BSO in 2010) were too soon after the SCI to take account of all of its findings. The forthcoming assessments of the Tahmoor South Coal Project and the Dendrobium Mine Extension Project provide the next opportunity to do so for substantive mining projects[7]. However, insight into progress since the SCI is provided in instruments such as SMPs and EPs, and reports, notably the PSM study report (Sullivan & Swarbrick, 2017), the 2014 NSW Chief Scientist & Engineer catchment cumulative impacts report (NSW Chief Scientist & Engineer, 2014), industry publications and submissions to this Panel.

Based on the information reviewed by the Panel and its discussions with stakeholders, the Panel concludes that there have been significant improvements since 2008 in integrating the various scientific studies and disciplines involved in subsidence impact assessment and management. These improvements have been facilitated by providing disciplines with a common platform for distinguishing between subsidence effects, impacts and consequences and by the multidisciplinary composition of inquiry and review panels (such as in the case of the MCP PAC, the BSO PAC, the Independent Review of Coal Seam Gas Activities in NSW (which encompassed the catchment cumulative impacts report) and this Panel. However, as evident, for example, when considering issues such as the height of fracturing (Part 1 Report §4.3), the relationship between groundwater and surface water and the consequences of mining impacts on swamps, there is still some way to go to achieve full integration.

2.2 PREDICTION OF SUBSIDENCE EFFECTS AND IMPACTS

2.2.1 Subsurface subsidence

The SCI had regard to the composite geotechnical/groundwater conceptual model (Figure 2) when considering zones of deformation in the overburden above mine workings, noting that it was not a complete or universally accepted model. This and similar models are referenced

[6] An early example of TARPs being applied in the Southern Coalfield to manage environmental impacts was during the 2008 assessment of MOD 6 for the Dendrobium Mine, when the applicant proposed a TARP structure to manage impacts to watercourses (Department of Planning and Environment, 2019). The Department, in consultation with relevant agencies, included a requirement to adhere to the TARP structure within the modified development consent for various contingency plans to avoid, minimise, mitigate or remediate impacts on watercourses and swamps. These plans included a Watercourse Impact Monitoring, Management and Contingency Plan and a Swamp Impact Monitoring, Management and Contingency Plan.

[7] The Russel Vale Underground Expansion Project was much smaller in comparison, involving only eight longwall panels and the PAC determined (in 2015) that it required more work and assessment before it could be determined. The Hume Coal Project is at the extreme southern end of the Southern Coalfield, with areal extent, predicted surface subsidence and exposure to natural features all restricted, so that the SCI findings find limited application.

extensively in literature, have featured in a number of environmental impact statements (EIS) and assessments prepared for mining proposals in NSW, and continue to undergo refinement. It is important to appreciate that they are conceptual and need to be applied with caution for geotechnical and groundwater purposes for reasons discussed in the Part 1 Report.

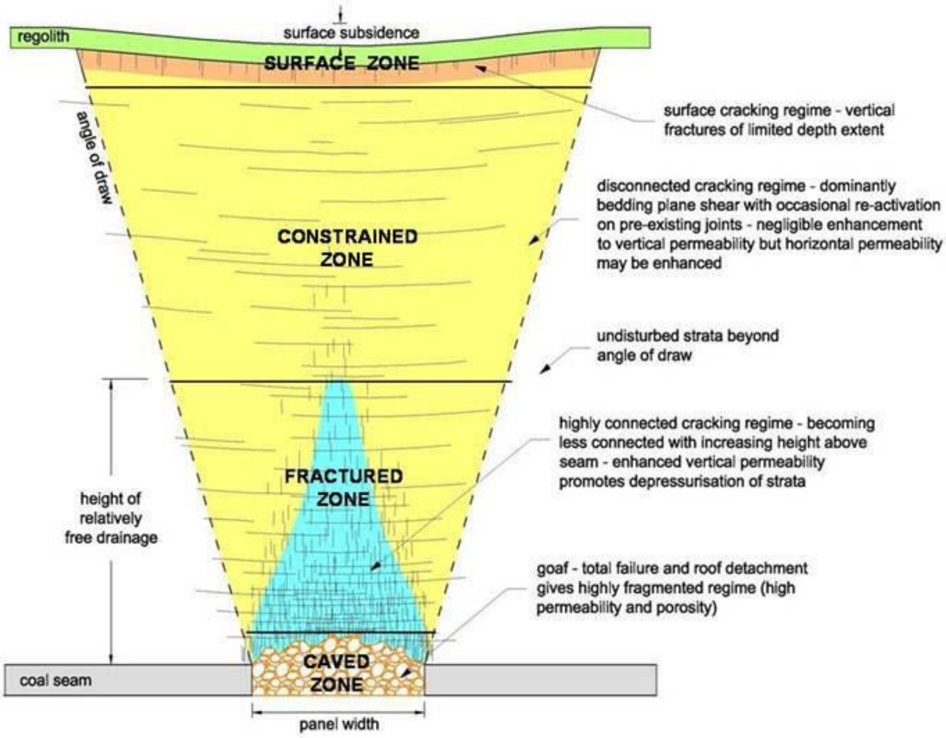

Figure 2: Conceptual model of caving and the nature of fracturing above a mine excavation
Source: reproduced from SCI Report

The issue of connective fracturing from mine workings through to the surface was not a particular concern at the time of the SCI and was not addressed in any detail in the report. Subsequently, the impact of mining on groundwater and surface water has assumed a very high profile in NSW. This has prompted a range of field studies and further research centred on site investigations supported by numerical modelling. There have been major efforts over the last decade by both Dendrobium and Metropolitan mines to employ up-to-date 3-dimensional (3D) groundwater models and best practice modelling methods undertaken by specialists, with expert peer review. The models have continued to improve in accuracy and predictive capacity. However, as with any modelling, limits remain and the assumptions must be scrutinised carefully. One of these assumptions relates to the height of complete groundwater drainage.

The height of complete groundwater drainage is an important consideration in groundwater modelling and assessing the impacts of mining on groundwater and surface water. Since the SCI, two empirically based equations have been developed in Australia for this purpose, namely the Tammetta equation (Tammetta, 2013) based on a groundwater approach and the Ditton Geotechnical Services (DGS) equations (DGS, 2013; Ditton & Merrick, 2014) based on a geotechnical approach. However, considerable controversy and confusion have surrounded their predictive capacities in the Special Areas.

The Panel has given detailed consideration to the equations in the Part 1 Report and concluded that it cannot endorse either at this point in time. For a range of reasons, neither or either may ultimately prove to be sufficiently reliable. It recommended erring on the side of caution and deferring to the Tammetta equation until:

1. field investigations quantify the height of complete drainage at Metropolitan and Dendrobium mines; and/or
2. geomechanical modelling of rock fracturing and fluid flow are shown to be sufficiently reliable for informing the calibration of groundwater models at mine sites in the catchment.

The Panel considers both of these to be research priorities for informing future assessments of mining in the catchment.

2.2.2 Conventional surface subsidence

The SCI classified techniques for predicting surface subsidence under the categories of empirical, analytical/numerical and hybrid. These classifications stand, with the major developments over the last decade being the empirical based Incremental Profile Method (IPM) becoming the dominant prediction technique and the increased use of numerical modelling to support aspects of subsidence prediction. The SCI concluded that the IPM was one of a number of techniques that was capable of producing reasonably accurate predictions of vertical displacement, typically within ±150 mm. This remains the case but there have been some notable exceptions.

Tahmoor Colliery, located in the Southern Coalfield, has a history of success with the IPM. However, in 2008 vertical displacement approached 1,150 mm over one longwall panel as compared to a predicted value of the order of 500 mm. Gale and Shepherd (2011) described the circumstances and concluded that the abnormal subsidence was consistent with localised weathering of joint and bedding planes above a depressed water table adjacent to an incised gorge.

In 2009, a need was identified at Springvale Colliery in the Western Coalfield of NSW to increase subsidence predictions based on the IPM by 30% in the vicinity of lineaments (Galvin, 2017b). In a third case, noted in the Part 1 Report, the maximum vertical displacement at many locations over LW 9 and LW 10 in Area 3B at Dendrobium Mine was up to 1.3 times that predicted by the IPM. The exceedances were thought to be due most probably to the increased depth of cover and wider longwall panels in the area, requiring recalibration of the IPM for these conditions (MSEC, 2016a).

The three cases illustrate that the prediction of conventional subsidence effects is not a precise science. The accuracy of alternative subsidence prediction methods is also prone to factors such as undetected changes in geological conditions, unexpected responses to geological conditions and calibration issues. Subsidence effects and their associated impacts may still occasionally be significantly underestimated, irrespective of the prediction technique. Therefore, management plans need to make provision for the early detection and control of the elevated risk that low-frequency events can present when mining in areas sensitive to subsidence impacts, such as in the Special Areas. This is especially the case when utilising longwall mining since the method is inflexible to immediate changes in mine layout to address these types of deviations.

Once a profile of predicted vertical surface displacement has been derived, it can be processed in a variety of ways to produce predictions of the type, location and magnitude of surface strains. These predictions are important for informing assessments of the consequences of mining-induced surface cracks for surface features, including watercourses and swamps. At the time of the SCI, impact and consequence predictions were generally based on conventional tensile strain and compressive strain being located in distinct non-overlapping zones as shown in Figure 14 of the SCI Report, reproduced as Figure 8 in the Part 1 Report. However, it was recognised at the time that due to factors such as cross bedding and buckling of thin beds of near-surface strata, there could be significant deviation in the field from these idealised responses to mining. Subsequently, these variations have been subjected to stochastic analysis which now provides an improved platform for better assessing impact likelihood and consequence (Barbato & Sisson, 2011; Barbato, 2017; Barbato et al., 2017).

2.2.3 Non-conventional surface subsidence

The reliable prediction of non-conventional subsidence effects continues to present significantly greater challenges than the prediction of conventional subsidence effects, particularly in respect of valley closure which is a critical parameter in regard to the integrity of watercourses, swamps and other features located on valley floors. This situation persists despite considerable research having been undertaken into the prediction of valley closure since the SCI. This included a large research project funded by the Australian Coal Association Research Program (ACARP) in response to the findings of the SCI. The research by Kay (2014) involved extensive field studies and statistical analyses that resulted in an improved understanding of the mechanics of valley closure and a revised and more complex prediction methodology compared with the previous 2002 methodology of Waddington and Kay (2002). However, the mining industry has continued to use the latter because the two methodologies produce similar predictions in magnitude and the 2002 method is simpler to use and aids in making comparisons with past findings (Kay, 2019).

The prediction of valley closure is complicated because there are many factors which can influence how a valley responds in the zone of influence of mining, not all of which are well understood. The more fundamental factors were identified in the SCI Report and they generally remain current. Additional factors affecting the development of valley closure are described in Kay (2014) and Barbato, Brassington, and Walsh (2014).

The level of uncertainty associated with the prediction of valley closure is illustrated in Figure 3, which shows the extensive disparities between predicted and measured valley closures and the associated levels of confidence in predictions. For the most part, the prediction methodology significantly over-predicts valley closures. It is applied conservatively using an upper bound approach based on envelopes constructed over measured maximum or worst case outcomes. However, total measured closure across a valley has found limited use in managing subsidence impacts within valleys.

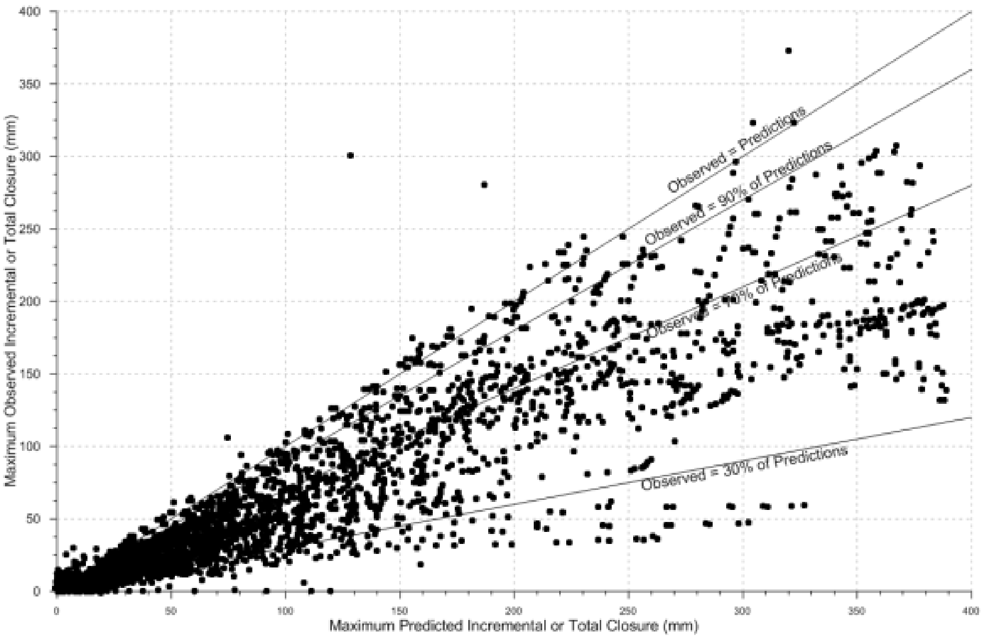

Figure 3: Predicted versus measured closure data base
Source: Kay and Waddington (2014)

Two basic reasons for this are, firstly, because closure is typically defined as the greatest reduction in distance between any two points on the opposing valley sides (MSEC, 2019b) and the location of these points is not known ahead of mining, there is uncertainty as to where to install monitoring lines to measure total valley closure. Secondly, and as illustrated in Figure 4 for the Waratah Rivulet at Metropolitan Mine, horizontal movement associated with valley closure is not distributed uniformly across a valley. Therefore, total measured closure is not representative of closure and associated ground strains at specific locations within the valley, such as across watercourses and swamps.

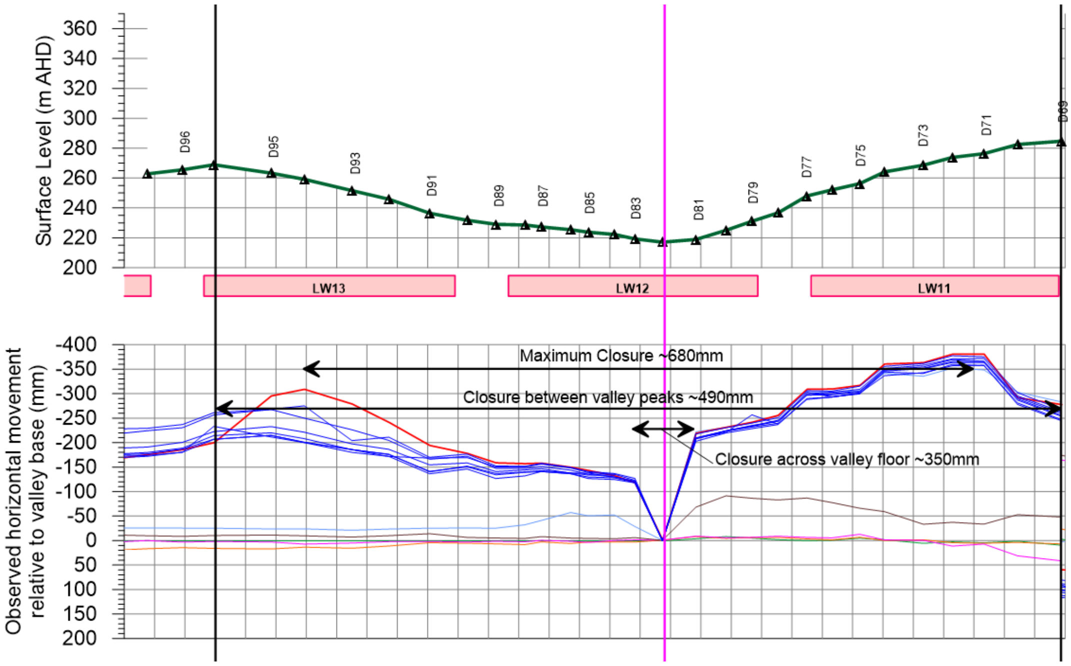

Figure 4: Observed horizontal movement at Waratah Rivulet, measured relative to the base of the valley
Source: MSEC (2019b)

Because of the challenges in measuring total valley closure, predicted valley closure has been utilised since the SCI for impact assessment on rockbar-controlled streams in the Southern Coalfield. This unusual approach was brought to prominence during the assessment of the MCP in early 2009. The impact assessment for the project presented in the Environmental Assessment (EA) and expanded upon in response to MCP PAC inquiries was premised on increased rockbar leakage not having been recorded up to that time at sites that had predicted total closure values of less than 200 mm. The MCP PAC concluded that:

> "*Because the 200mm closure limit is an outcome of a prediction methodology that is under development, it is subject to change as the prediction methodology evolves"* (PAC, 2009).

The MCP PAC questioned whether closure and upsidence behaviour in the Project Area should conform to past Southern Coalfield experience given that conventional subsidence effects were greater in the Project Area than recorded elsewhere in the Southern Coalfield. It was advised that:

> "*There is some probability, regardless of the approach, that potential impacts could occur at predicted closure values less than the minimum predicted total closure of 200 mm that has been identified to date".*[8]

The assessment process required the MCP PAC to evaluate the merits of a modified mine plan submitted as part of the proponent's Preferred Project Report (Peabody Energy, 2009) in response to PAC deliberations. The PAC made an assumption for the purposes of comparing mine plans that a performance measure of negligible environmental

[8] Responses to Planning Assessment Commission Queries. Question 16. 24 February 2009 (PAC, 2009)

consequences for watercourses would be achieved in circumstances where valley closure was predicted to be less than 200 mm. It stated that:

> *"The Panel is aware from submissions relating to other operations in the Southern Coalfields that occasional "minor" streambed fracturing and iron staining have been recorded where predictions of closure have yielded values of 200mm or less, albeit that fracturing has not affected the integrity of rockbars".*[9]

Subsequently, this approach appears to have become the basis for interpretations and/or expectations by some stakeholders that a performance measure of 'minor', and even 'negligible' in some cases, will be satisfied in situations where total valley closure is predicted to be less than 200 mm or where less than a certain percentage of pools lose their water retaining capacity. It is apparent from submissions that this situation is giving rise to inconsistent performance measures, confusion and debate and that it warrants clarification by government for the purpose of providing unambiguous, quantifiable and measurable performance measures, consistent with requests such as that of WaterNSW[10]. The following aspects give insight into the nature of the problem and inform the Panel's conclusions and recommendations.

The impact assessment process for watercourses adopted in the BSO EA was based on the same approach as in the EA for the MCP but with stream impacts now being categorised as one of three types, namely:

- Type 1: nil or negligible impacts
- Type 2: isolated fracturing, gas releases or iron staining
- Type 3: fracturing which has resulted in pool water levels dropping more than expected after considering the rainfall and surface and groundwater flow conditions.

The correlation between the three types of stream impact and predicted total valley closure at the time is shown in Figure 5. The developers of this Figure noted that it could not be assumed that all rockbars will fail at 200 mm predicted closure or that all pools will be drained when the predicted total closure value is above 200 mm (MSEC, 2009). Similarly, they noted that it was possible that Type 3 water loss impacts could in the future be observed at a site where the predicted total closure was less than 200 mm even though none had been observed up to that time.

The developers advised that:

> *Current [August 2009] reference to the 200 mm predicted total closure value should therefore be viewed as an indication of low probability (10% as detailed below) of [Type 3] impact rather than certainty* (MSEC, 2009).[11]

That advice was based on the August 2009 curve plotted in Figure 6, which indicated that although no Type 3 impacts had been noticed up to that time when the predicted total closure was less than 200 mm, 4 out of 37 cases or 11% of the available database experienced Type 3 impacts once the predicted total closure was 215 mm.

The Panel advises that care is required in interpreting and applying the relationships displayed in Figure 6. The probability of an impact derived from a regional data set does not necessarily equate to the same probability on a site-specific basis. Regional data sets can dilute or mask the probability of outcomes on a site-specific basis. This appears to be the situation in the case of Eastern Tributary at Metropolitan Mine.

[9] PAC (2009), p. 34
[10] Submission No. 30, WaterNSW
[11] p. 47

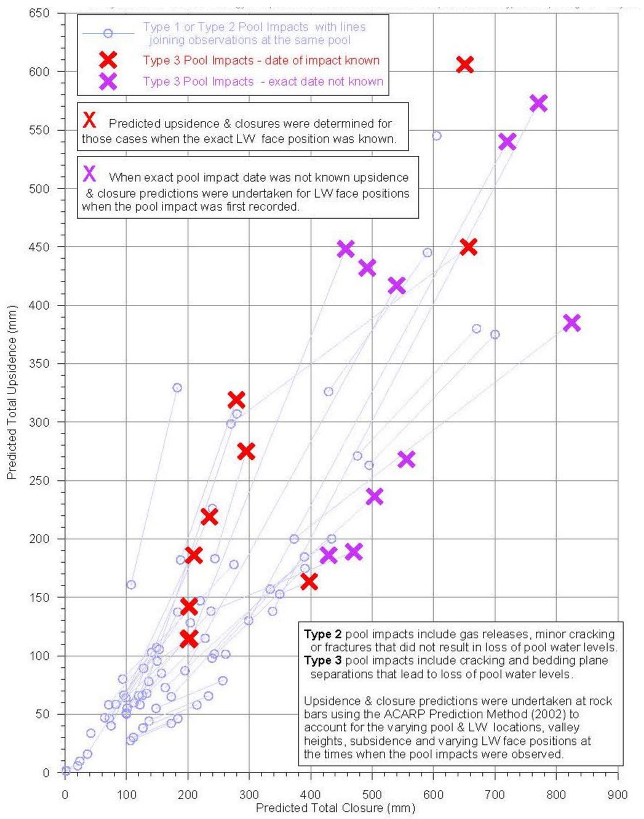

Figure 5: Correlation between predicted total closure and total upsidence at time of pool impacts for Southern Coalfield collieries
Source: MSEC (2009), reproduced as Figure 4.21 in BSO PAC report (DoP, 2010)

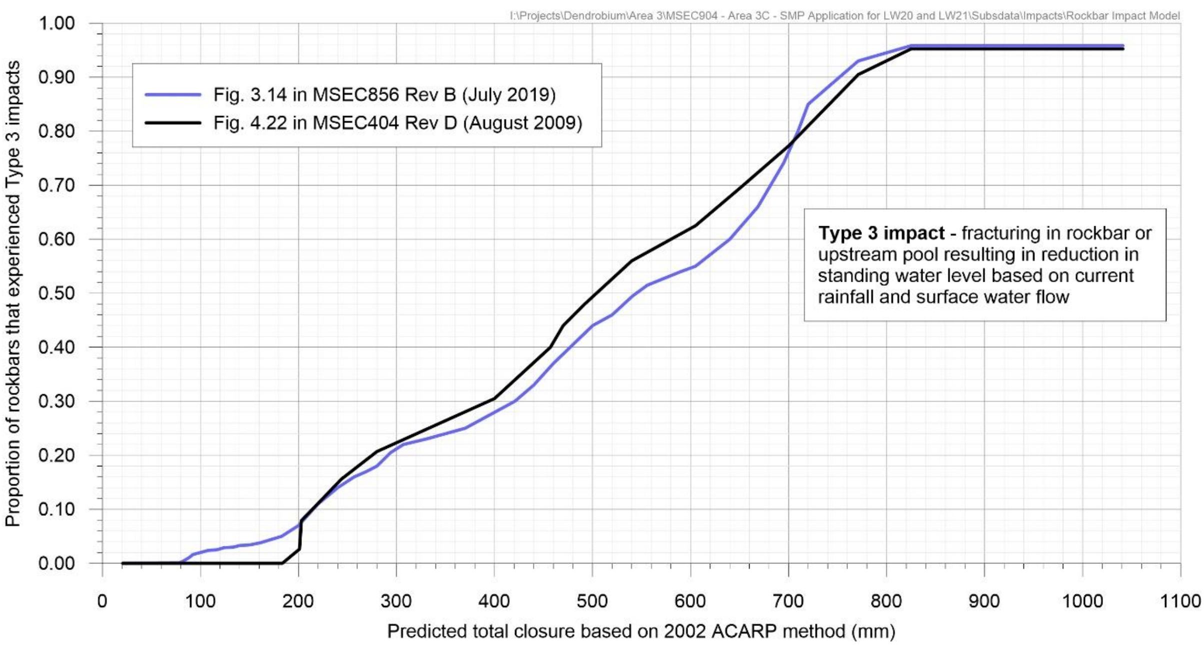

Figure 6: Relationship between predicted total valley closure and proportion of rockbar controlled pools that have experienced Type 3 impacts
Source: (MSEC, 2009, 2019c)

The BSO PAC noted that the performance criteria proposed in the BSO EA for the lower Georges River were:

> *"Minor fracturing of controlling rockbars, with negligible diversion of water from associated pools. Potential for fracturing of stream bed and consequent stream flow diversion in stream reaches between controlling rockbars. Localised impacts on stream water quality. Strata gas release."*

and that this was to be achieved by:

> *"Longwall layout design to achieve a maximum predicted closure of 200 mm at controlling rockbars. Implementation of stream remediation measures … where subsidence results in the diversion of stream flow in stream reaches between controlling rockbars, and where the stream features are such that the remediation measures are considered technically feasible."*

Further, the BSO PAC noted that the impact assessment methodology used in the EA applied only to pools controlled by rockbars and that:

> "…*in fact the mechanism need not be so specific. Any new flow path away from a pool can lead to loss of water from the pool and this applies equally to pools formed behind rockbars, riffles, boulder fields or any other channel feature"* (PAC, 2010).

In responding to the Panel's questions, the Proponent advised that in addition to there being 169 pools upstream of rockbars, another 175 pools were upstream of boulder fields and another 14 upstream of other obstructions. The Proponent reported variously that:

> *"…boulder field controlled pools are less likely to have increased leakage as a result of subsidence movements"*

and if

> *"…leakage through the sediments is enhanced due to cracking of the sediments they are more likely to infill with local and transported sediments during subsequent flow and flood events within the stream"*

and

> *"Where boulder fields or sediment accumulations occur over bedrock there could be fracturing of the underlying bedrock as a result of subsidence movements. These fractures are likely to infill over time due to the immediate availability of sediments to the fracture network".*

The BSO PAC reported that these and other related statements were not supported in the EA by any factual observations or measurements and, therefore, PAC had no option but to consider them conjecture. It also noted that the Proponent did not commit to pools upstream of boulder fields experiencing negligible impacts, being the performance standard applied to rockbars throughout large portions of the BSO Study Area.[12] The PAC concluded that:

- *"The Panel is not satisfied that stream values are protected by a focus on limiting fracturing only at rockbars but allowing fracturing elsewhere in the valley floor."*
- *"The Panel does not support reliance on remediation after damage as a primary management measure."*

Subsequently, Type 3 events have been recorded at predicted total valley closure values of less than 200 mm at both Metropolitan and Dendrobium mines. All occurrences up to July 2019 are reflected by July 2019 curve in Figure 6, which shows that Type 3 events have been recorded at predicted total valley closure values as low as 80 mm. This was at Metropolitan Mine (MSEC, 2019a). The plot is also based on five Type 3 impacts recorded

[12] The Panel notes the close similarities these statements have to past opinions, since called into serious doubt that fracture networks beneath swamps are likely to heal naturally due to the ingress of sediment.

beyond the footprint of longwall panels at Dendrobium Mine. One of these events was associated with a predicted valley closure of 95 mm and the other four events at predicted values ranging from 140 to 165 mm (MSEC, 2019c).

The Panel notes that the descriptions of Type 1 and Type 2 impacts correspond closely with, respectively, the definitions of the terms 'negligible' and 'minor' in mining consents. It also notes that the description of a Type 2 impact is consistent with the description in the BSO EA of minor fracturing being associated with negligible diversion of water from associated pools. On these bases, it concludes that a Type 3 impact should constitute an exceedance of a performance measure of minor environmental consequence.

The Panel notes, however, that Wongawilli Creek (which runs between Area 3A and Area 3B at Dendrobium Mine) has a performance measure of minor environmental consequences that is defined in terms of minor fracturing and minor impacts on water flows, water levels and water quality (see Table 4, Part 1 Report). Nevertheless, the rockbar model presented in Figure 6 has been used to set back longwall panels from Wongawilli Creek in Areas 3A and 3B so that the maximum predicted closure was 200 mm and, therefore, the assessed rate of impact for the pools and channels was less than 10% (MSEC, 2019c).

This appears to have led some to conclude that a performance measure of 'minor' is now associated with less than 10% of pools experiencing Type 3 impacts. However, one needs to be aware that the Subsidence Impact Performance Measures for Dendrobium Mine also make provision for meeting the requirements of performance measures by either avoidance, mitigation of remediation (see footnote in Table 4, Part 1 Report). South32 (Dendrobium Mine) has advised variously that:

> *"The conditions for the exceedance of performance measures for Wongawilli Creek are:*
>
> - *structural integrity of the bedrock base of any significant pool or controlling rockbar cannot be restored",* [13]
>
> *"Fracturing in WC Pool 43a has been reported in the Longwall 13 EoP Report as a Level 3 trigger as per the pool water level TARP (South32 2018[a]). WC Pool 43a represents less than 10% of Wongawilli Creek;*

and

> *"Although a fracture caused by mine subsidence is present in the base of Pool 43a, water levels in the pool were declining prior to that fracturing occurring."*[14]

In 2016, Peabody reported that valley closure impacts on the Eastern Tributary were considered to be anomalous in that more than 15% of pools on the Eastern Tributary have experienced loss of pool water levels at predicted closure values of less than 200 mm and that, on their own, the impacts for the Eastern Tributary are outside of the predictions of the empirical based model (Peabody, 2017a). The Panel does not subscribe to this view. The SCI identified that the extent of subsurface fracturing at the nearby Waratah Rivulet tended towards one end of the spectrum and suggested that a combination of near-surface geology and the actual valley shape/profile may have had some influence. It went on to state that differences in response confirm the importance of detailed site-specific investigations in order to determine, firstly, the subsidence effects, and then the likely impacts on the natural features. Similarly, and as noted earlier, the MCP PAC questioned whether valley closure should conform to past Southern Coalfield experience given the elevated levels of conventional subsidence effects in the Project Area.

[13] The Panel is of the understanding that the SMP for Dendrobium only has regard to the *structural integrity of the bedrock base* in respect of nominated swamps, viz: *Swamps 1a, 1b, 5, 8, 11, 14 and 23 - maintenance or restoration of the structural integrity of the bedrock base of any significant permanent pool or controlling rockbar within the swamp*

[14] South32 Response to Water NSW Submission (No. 30) on the Initial Report of the Independent Expert Panel for Mining in the Catchment, 14 August 2019

Two additional issues associated with non-conventional subsidence that need to be considered in more detail going forward are:

- The potential for regional movement on bedding planes. This issue was identified in the SCI. More recently, the PSM study also raised the possibility that large scale block movements possibly governed more locally by the presence of geological structure or structures are causing a deviation from the more consistent movements expected from conventional subsidence (Sullivan & Swarbrick, 2017). The consultants identified a need to install additional monitoring instrumentation at Dendrobium Mine as a matter of priority and to commence monitoring as soon as practical.
- The practicality and enforceability of specifying water quality and iron staining as components of performance measure for only a proportion (or percentage) of the length of a watercourse, since unlike physical damage to the environment, these types of impacts may not be able to be contained within a close distance to the mining footprint.

2.3 CONCLUSIONS

a. The distinctions drawn by the SCI between subsidence effects, subsidence impacts and subsidence consequences have been refined and generally adopted by stakeholders in NSW and are working well.

b. The challenge identified in the Southern Coalfield for the mining industry and its consultants to move to a new generation of predictive capacity which is essentially quantitative in nature is a work in progress.

c. Subsidence impacts and consequences for groundwater, surface water and swamps have assumed a higher profile since the SCI.

d. There have been significant improvements since 2008 in integrating the various scientific studies and disciplines involved in subsidence impact assessment and management, but there is still some way to go.

e. Height of fracturing leading to groundwater depressurisation has emerged as a critical issue since the SCI. It has significant implications for calibrating numerical models and assessing current and long term subsurface and surface subsidence impacts and consequences and requires further research.

f. Effects resulting from conventional surface subsidence behaviour and their impacts are well understood and reasonably predictable. Nevertheless, management systems still need to make provisions for those occasions, albeit rare, where subsidence effects are significantly under-predicted.

g. Despite substantial research, there has been little advance in the reliable prediction of non-conventional subsidence effects and impacts. There are considerable disparities between predicted and measured valley closures, reflecting the complex and site specific nature of ground responses to mining in Southern Coalfield conditions. The gaps in the knowledge base continue to be managed on the basis of designing to recorded worst case outcomes.

h. There is increasing recognition of the potential for geological discontinuities to act as or become conduits for groundwater flow.

i. Since the SCI, likelihood relationships for the Southern Coalfield have been derived between predicted total valley closure and the proportion of fractured rockbars that control pool water levels on watercourses. However, this coalfield-wide approach can mask site specific behaviours, does not provide insight into the scale and distribution of the consequences associated with the fracturing and loss of water retention properties of rockbars, and does not address the potential for water loss from pools formed behind boulder fields. Nor does it consider water loss from all other parts of a watercourse. Hence, the prediction of impacts on watercourses on the basis of only impacted rockbars is an incomplete process.

j. The idea that a performance measure of ‘minor’ will be satisfied in situations where total valley closure is predicted to be less than 200 mm or where less than a certain percentage of pools lose their water retaining capacity is questionable in circumstances other than when consent conditions make provision for meeting the requirements of performance measures by avoidance, mitigation or remediation.

k. Dendrobium Mine was approved almost two decades ago and its consent conditions, due to expire in 2030, are not fully representative of contemporary consent conditions, notwithstanding that ongoing mining is regulated through contemporary SMP approvals.

l. Since the SCI, there has been a progressive move away from specifying performance measures in qualified terms, and towards more quantifiable terms. There are still opportunities for government to improve the effectiveness of performance measures, especially for watercourses and swamps, by specifying them in terms that are less ambiguous and more quantifiable and measurable.

m. Going forward, there is a need to consider the potential for regional movement on bedding planes and the practicality of specifying water quality and iron staining as components of performance measure for only a proportion (or percentage) of the length of a watercourse, since these types of impacts may not be able to be contained within a close distance to the mining footprint.

2.4 RECOMMENDATIONS

1. The concept of subsidence effects, subsidence impacts and subsidence consequences should continue to be embedded in mining assessment processes
2. There is a need for a higher focus on the assessment of regional impacts and consequences associated with groundwater depressurisation, including if and how far these impacts and consequences might extend beyond the mining footprint.
3. Research is required into:
    a. quantifying the height of complete drainage above mine workings
    b. the reliability of geomechanical modelling of rock fracturing and fluid flow for informing the calibration of groundwater models and, thus, also replacing the use of the Tammetta and/or Ditton equations
    c. establishing the potential for regional movement on bedding planes and the potential consequences that this may have, especially in the vicinity of water storages.
4. Management plans need to make provision for the early detection and control of the elevated risk that variance between predicted and measured subsidence effects, both conventional and non-conventional, when mining in areas sensitive to subsidence impacts, such as the Greater Sydney Water Catchment. This is especially the case when utilising longwall mining since the method is inflexible to immediate changes in mine layout to address of deviations from predictions.
5. Impact assessments for watercourses should consider not only rockbars and the pools behind them, but all features along the full lengths of watercourses.
6. The Department should review the practicality of specifying water quality and iron staining as components of performance measure for only a proportion (or percentage) of the length of a watercourse.

3 GROUNDWATER AND SURFACE WATER

Knowledge about the impacts and consequences of mining on groundwater and surface water systems in the Special Areas has increased significantly since the SCI due to investments in monitoring, analyses and computer modelling of those systems. Although significant knowledge gaps remain, there is increasing knowledge of the potential for interaction between groundwater and surface water in areas affected by mining. This includes the influence of groundwater depressurisation on surface water flows, and the influence of surface water on mine inflows. Therefore, groundwater and surface water are considered together in this chapter.

The Panel's Terms of Reference require it to have a particular focus on cumulative impacts on water quantity in the Special Areas. Some submissions to the Panel hold out an expectation that the Panel can provide an assessment of cumulative mining impacts. As discussed in this Chapter, this is simply not feasible given the current state of knowledge of historical mining operations. Other strategic questions related to cumulative impacts assessment including data management are covered in Chapter 5.

The potential consequences of mining on groundwater and surface water in the Special Areas covered in this Chapter are:

- **Groundwater depressurisation**: groundwater pressures have declined due to mining impacts. These declines are the symptom of water loss to new void spaces in the overburden and changes in overburden hydraulic conductivity that alter flow directions, which may cause loss of baseflow to watercourses.
- **Surface water diversions:** surface water enters the ground due to mining related impacts and in many cases re-emerges downstream within the Special Areas. This results in localised water loss, with potential aesthetic, ecological and water quality consequences. These losses may occur from watercourses or from rainfall runoff (as overland flow) before it reaches a watercourse.
- **Surface water permanent losses:** surface water enters the ground due to mining impacts and a proportion is diverted outside of the Special Areas (including via mine dewatering systems) or is stored long-term in the ground. This results in some reduction of flows to Greater Sydney water supplies, as well as potential aesthetic, ecological and water quality consequences. These flow losses are permanent in the sense that the water loss is not recovered into the Sydney water supply system. Losses vary from year to year and may reduce after the cessation of mining.
- **Groundwater repressurisation**: groundwater pressures may recover towards pre-mining conditions in the decades following closure of the mine. This has the potential to increase discharges of poor quality water from some sites into the Special Areas for an unknown period of time.
- **Water quality:** although water quality is not a primary focus of the Panel's Terms of Reference, deterioration in the quality of water flowing into the catchment in the long term (following mine closure) has the potential to affect water availability and/or costs of water treatment.

3.1 OVERVIEW OF INITIATING MECHANISMS

The creation of an excavation below the water table can affect groundwater in a number of basic ways. In all cases, because the fluid pressure in an excavation is much lower than that of the fluid that originally occupied the space, a flow system is established with the excavation acting as a sink into which surrounding groundwater flows. The rate of flow and observed extent of depressurisation depend on the hydrogeological properties of the rock mass. If the excavated area is sufficiently large, the spatial extent and rate of flow into the sink can be enhanced by the formation of fractures.

Depending on mining height and depth of mining, these enhanced flow paths may extend through to the surface thereby providing potential for surface waters to be redirected into the subsurface and into mine workings. Other potential flow paths include flow via the shallow fracture network to the limit of the subsidence zone before returning to the surface (surface water diversion) possibly into adjacent catchments (permanent loss). Surface water flow diversions and permanent losses may also be caused by reduction or reversal of groundwater pressure gradients in the vicinity of water reservoirs.

Figure 7 conceptually illustrates some of the potential short term and the very long term mining implications for groundwater, surface water and swamps in the Southern Coalfield. Figure 7A shows the initial stage associated with depressurisation and leakage of surface water into a mine. Water flows into mine workings in the short term from the coal seam and adjacent strata and from drainage of the fracture networks associated with subsidence. The Figure depicts the direct contributions from rainfall on these fracture networks if they daylight to the surface and the diversion of water from watercourses and swamps that become directly or indirectly connected to the fracture networks.

Figure 7B illustrates the situation towards the end of a transitional stage (which may extend over many decades) following mine closure. It depicts how once the mine fills with water, the issue can transition from one of not only natural water inflow from the surface to mine workings but also water outflow from mine voids and sub-surface fracture networks back to the surface. In this regard, much depends on whether it is physically possible to confine water within the mine in order to reverse the long term effects of depressurisation. As shown conceptually in Figure 7B, the re-establishment of the water table depends on there being no overflow, or spill points, below the targeted elevation of the restored water table. Potential spill points include mine entries from the surface, geological discontinuities and mine fracture networks that daylight.

For a given panel width, the intensity and connectivity of mining-induced fractures decreases with distance above the mining horizon (Part 1 Report). This means that in circumstances of high topographic relief, such as in the Special Areas, if fracture network spill points do develop, they are more likely to be located in valley floors, where cover depth is least. In any event, irrespective of where a fracture network daylights, outflow is very likely to find its way to valley floors, from where it can report via watercourses to reservoirs.

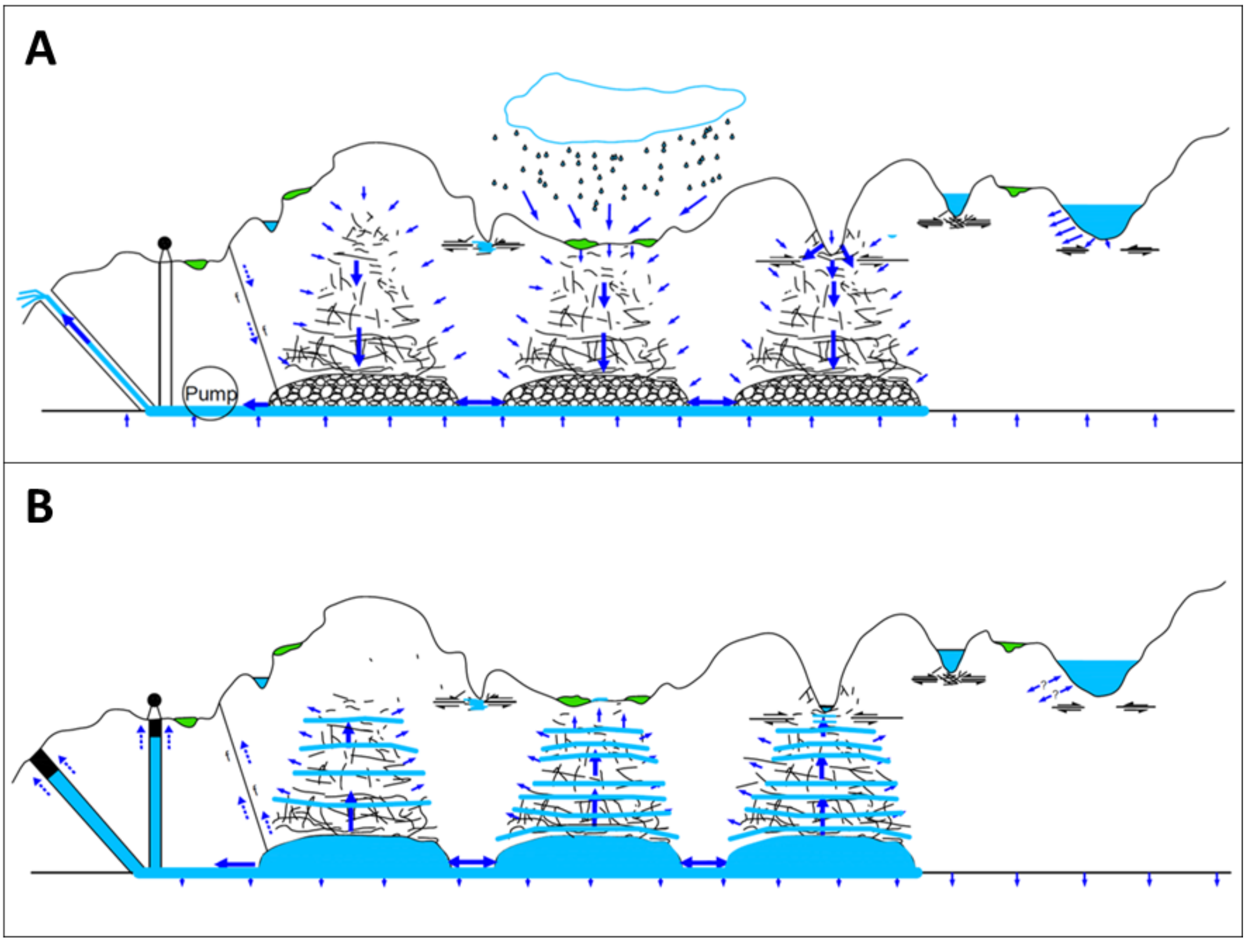

Figure 7: Schematic diagram of possible options for water inflow into mine workings in the short term and outflow in the long term, based on assuming that the height of connective fracturing is equal to excavation width on the basis of the overburden caving model inferred by Mills (2012) (the model can be applied to alternative definitions of the height of connective fracturing).

A. Pre-closure stage – water inflow options

B. Post-closure and sealing stage – water outflow options

3.2 EVIDENCE OF REGIONAL DEPRESSURISATION AND WATER LOSSES

3.2.1 Evidence of regional depressurisation

At the time of the SCI report, depressurisation was known to occur in and around an extracted coal seam [§4.2.4]. The report noted that:

> *"This depressurisation of aquifers in strata overlying the coal seam may be of little long term significance, providing that the aquifer is isolated from the surface drainage network of the water supply catchments and that there is no current or prospective use for the groundwater otherwise contained in the aquifer."*[15] *(p.75)*

The PSM study concluded that the Dendrobium Mine data supports widespread regional groundwater depressurisation[16] (Sullivan & Swarbrick, 2017). Data since 2017 have confirmed this and provided further information on potential consequences for surface water losses.

[15] p. 75
[16] *Regional groundwater depressurisation* is used here to describe the situation where depressurisation is observed over and to some extent beyond the mined area throughout the vertical profile (from the shallow aquifers down to the mine void)

In November 2017 at Dendrobium Mine, a TARP performance indicator was triggered in relation to a previously recorded fracture in the bedrock of Wongawilli Creek and low water level in Pool 43a. This pool is located under main development headings and between LW 6 on one side of the headings and LW 9 on the opposite side, as shown in Figure 8. By August 2018, when mining had progressed to completion of LW 13, a 1,543 m length of Wongawilli Creek had developed zero or discontinuous flow (ICEFT, 2018b, 2018c, 2018a; South32, 2018d). Following the TARP trigger, Dendrobium Mine undertook additional monitoring and analysis. It was observed by the mining company in the End of Panel Report for LW 13 that:

> "*Groundwater levels in Hawkesbury Sandstone and upper Bulgo Sandstone adjacent to and below Wongawilli Creek have declined as a result of mining in Areas 3A and 3B. Groundwater levels in the upper Hawkesbury Sandstone have not been affected to the same extent. Given that the Bald Hill Claystone and upper Bulgo Sandstone are exposed in the Wongawilli Creek valley upstream of Pool 43a, depressurisation of those strata are likely to result in a decrease in groundwater discharge (baseflow)*"

and

> "…*the steady decline in water levels at Pool 43a since 2012 appears independent of the rainfall trends and may indicate progressive local flow diversion and/or baseflow reduction. Based on the information reviewed here, the latter mechanism (baseflow reduction) may be dominant… Although the data are sparse, there does not appear to be a clear step-change in water levels associated with the fracturing event*" (South32, 2018a).[17]

The Panel agrees with the interpretation that groundwater depressurisation due to mining is likely to be the reason for reduced baseflows and reduced pool levels in Wongawilli Creek. This interpretation is also supported by the mining company's groundwater model, which predicts baseflow loss from Wongawilli Creek (HydroSimulations, 2018a). The mining company notes that no baseflow loss has been detected at the downstream Wongawilli Creek (WWL) gauge (Figure 8) (South32, 2018a).[18] The Panel's view is that the depressurisation and loss of baseflow observed further upstream will most likely result in baseflow loss at the WWL gauge and, therefore, the apparent absence of baseflow loss at that gauge is likely due to uncertainty in the surface flow measurement and modelling at WWL. It is possible, however, that enhanced horizontal hydraulic conductivity due to fractures and bedding plane shears acts to sustain baseflows.

The regional depressurisation and its likely consequences for watercourse flows and surface water losses particularly in Wongawilli Creek have been the subject of concern in submissions to the Panel. The Panel's view is that these concerns are well-founded, and that the performance measures in the Dendrobium Mine SMP approval and in the modified Consent Condition (Table 2) do not sufficiently put measurable limits on the loss of surface water (both diversions and permanent losses) due to depressurisation. The status of Wongawilli Creek relative to the performance measure of no more than minor environmental impacts is especially difficult to judge when multiple and/or widespread impacts are involved, as has been the case. The limitations of the performance measures in these respects is due to past limitations in knowledge about height of fracturing and potential for cumulative impacts on surface water diversions and losses. All future mine approvals should include performance measures that are objective and can more precisely determine the cumulative impacts and consequences of a mine project progression. Performance measures should include changes in pressure and/or pressure gradients where these have the potential to impact on surface water losses.

[17] p. 35-37
[18] p. 37

Data from Metropolitan Mine[19] show that depressurisation in shallow aquifers is less than at Dendrobium Mine. This is due to Metropolitan Mine's greater depth, significantly narrower longwall panels and lower height of mining.

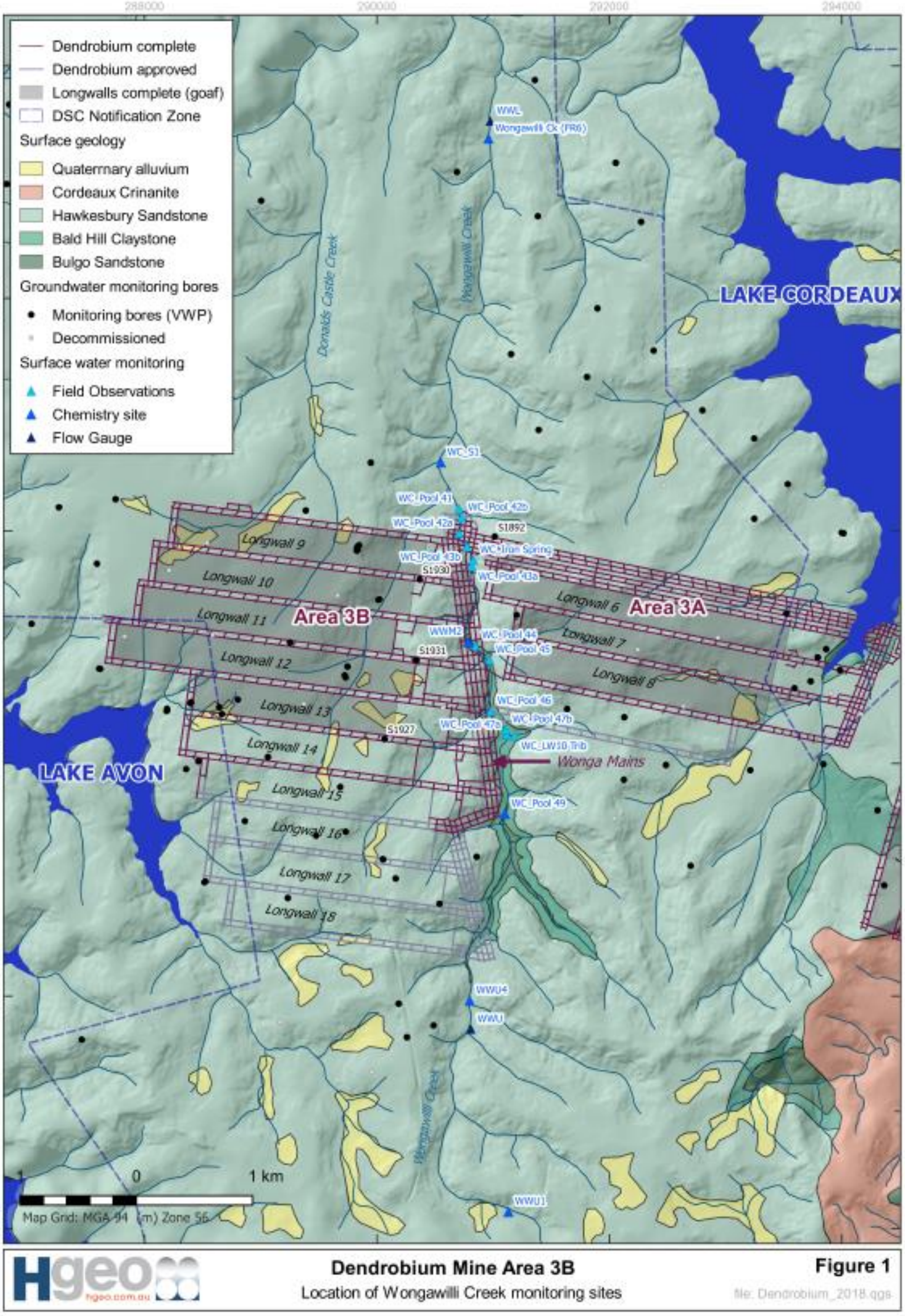

Figure 8: Location of Wongawilli Creek groundwater and surface water monitoring sites
Source: HGEO (2018)

[19] p. 58-64, Peabody (2018a)

Table 2: Subsidence Impact Performance Measures – Dendrobium Mine LW 17 Subsidence Management Plan Approval

Swamps	
Swamps 1a, 1b, 5, 8, 11, 14 and 23	Minor environmental consequences including: • *negligible* erosion of the surface of the swamps; • *minor* changes in the size of the swamps; • *minor* changes in the ecosystem functionality of the swamp; • *no significant* change to the composition or distribution of species within the swamp; and • *maintenance or restoration* of the structural integrity of the bedrock base of any significant permanent pool or controlling rockbar within the swamp.
Swamps 3, 4, 10, 13, 35a and 35b	No significant environmental consequences beyond predictions in the Subsidence Management Plan (2012).
Watercourses	
Waterfall WC-WF54	Negligible environmental consequences including: • *no* rock fall occurs at the waterfall or from its overhang; • *no* impacts on the structural integrity of the waterfall, its overhang and its pool; • *negligible* cracking in Wongawilli Creek within 30 m of the waterfall; and • *negligible* diversion of water from the lip of the waterfall.
Wongawilli Creek Donalds Castle Creek	Minor environmental consequences including: • *minor* fracturing, gas release and iron staining; and • *minor* impacts on water flows, water levels and water quality.
Water storages	
Avon Reservoir	Negligible environmental consequences including: • *negligible* reduction in the quality or quantity of surface water inflows to the reservoir; • *negligible* reduction in the quality or quantity of groundwater inflows to the reservoir; and • *negligible* leakage from the reservoir to underground mine workings.

Notes: *These performance measures apply to Longwalls 9 to 17. The Applicant may meet the requirements of this condition either by avoidance, mitigation or remediation. Most swamps and watercourse features are shown on the site and key natural features plan (see Appendix 1).*

Note: Dendrobium Mine Approval Modification 8 (2018) states that "*The Applicant must ensure the development does not result in reduction (other than negligible reduction) in the quality or quantity of surface water or groundwater inflows to Lake Cordeaux or Lake Avon or surface water inflow to the Cordeaux River at its confluence with Wongawilli Creek, to the satisfaction of the Secretary*."

3.2.2 Evidence of flow diversions

At the time of the SCI, the potential for mining-induced flow diversions was well known in general terms, although evidence was limited. The SCI described two general types of flow diversions:

- Diversions into a shallow, localised fracture network, where loss of flow from a surface water is likely to return to the system at some point downstream, which based on observations of the SCI Panel may vary from 20 m for specific rockbars to more than 200 m
- Diversions into deeper, dilated shear surfaces on bedding planes, where these form a conduit for lateral water flow, which may or may not report to the same catchment (i.e. it may become a permanent loss)

This general classification of flow diversions remains consistent with available knowledge. Since the SCI, there has been a substantial amount of additional pool level data collected over Dendrobium and Metropolitan mines. Recent surface water assessment reports include pool level reports for 23 pools on the Waratah Rivulet and 11 on the Eastern Tributary at

Metropolitan Mine (Peabody, 2017b), and 26 on Wongawilli Creek and its tributaries at Dendrobium Mine (South32, 2018b), as well as numerous pools on other watercourses in both these mining areas.

Since the SCI, surface fractures along Waratah Rivulet and surface water diversions from pools near undermined areas (above the maingate of LW 23) have been extensively reported. These impacts were predicted in the 2009 project approval application on the basis of predicted total valley closures. Downstream of the maingate of LW 23 there have been no reported surface diversions from Waratah Rivulet (MSEC, 2018). In the Eastern Tributary, however, a succession of pools has experienced water losses that were not predicted.[20]

At Dendrobium Mine, there have been a large number of TARP performance indicator triggers relating to fracturing and iron staining on tributaries of Wongawilli Creek and Lake Avon.[21] No performance measures apply to these tributaries. Flow diversions in the tributaries have been observed based on flow gauge data (ICEFT, 2018b, 2018c, 2018a; South32, 2018d).

3.2.3 Evidence of permanent surface water losses

Prior to 2000, the focus in regard to mining-induced water losses in the Southern Coalfield was largely confined to avoiding water inflowing to mines through hydraulic connections between the bases of the water reservoirs and mine workings and ensuring that mining did not impact the structural integrity of the dam walls. The Reynolds Inquiry into mining under stored waters in the Sydney Water Catchment was particularly concerned with this issue (Reynolds, 1976). The consequences of mining on flows into the reservoirs received little attention. At the time of the SCI, there remained a lack of data and knowledge on surface water flow losses. The SCI concluded:

> *"No evidence was presented to the Panel to support the view that subsidence impacts on rivers and significant streams, valley infill or headwater swamps, or shallow or deep aquifers have resulted in any measurable reduction in runoff to the water supply system operated by the Sydney Catchment Authority or to otherwise represent a threat to the water supply of Sydney or the Illawarra region. However, this does not discount the possibility that a reduction in runoff may be realised under certain conditions…"*

Since the SCI, a considerable database of permanent surface water losses has been developed. The losses include surface water diversions into the mines, leakage from reservoirs into the mines and loss of baseflow inputs to watercourses due to groundwater depressurisation. Reporting loss rates for the Special Areas is complex because the available loss estimates correspond to different time periods and/or catchment areas, and no estimates are available for most historical mines. Estimates of losses referred to in the Part 1 Report plus some supplementary data are summarised in Table 3. These data suggest that the recent loss rate totalled over the Dendrobium, Wongawilli and Russell Vale mines (in the Metropolitan Special Area) is an average of 8 ML/day; and for the Dendrobium Mine alone is less than 5 ML/day. Loss rates increase as the area of excavated coal seam increases, and vary over time depending on rainfall.

[20] See the TOR1 report for analysis of valley closure threshold criteria
[21] 17 reports of fractures, iron staining or pool water loss in the Dendrobium Impact reports from March 2018 to January 2019. Also see §3.1.1 South32 (2018a)

Table 3: Summary of estimates of water loss from the Special Areas to Dendrobium, Metropolitan, Russell Vale and Wongawilli mines

Mine	Loss metric	Source of estimate	Area included	Approximate time period included	Value (ML/day)
Dendrobium	Total mine water take	Measured mine void water balance	Areas 1, 2, 3A, 3B	2010-2018 average	6.2[1]
				Current	7.55[2]
	Diversion of surface flow into the mine	Disaggregation of total mine water take	Areas 1, 2, 3A, 3B	2010-2018 average	2.1[3,5]
				Current	3[4]
	Leakage from reservoir into mine	Groundwater flow analysis	Lake Avon	Near future (LWs 12 to 16)	0.73[4,6]
	Leakage from reservoir into mine	Groundwater modelling	Lake Cordeaux	Current and future	<0.1[7]
	Baseflow loss due to depressurisation	Groundwater modelling	All catchments in Special Areas affected by Areas 1, 2, 3A, 3B	2010-2020 average	1.0[4,8]
	Surface flow loss	Surface flow modelling and measurements	Wongawilli Creek, Donalds Castle Creek catchments overlapping Areas 3A and 3B	Last ten years	2.3[9]
Metropolitan	Total mine water take	Measured mine void water balance		2009-2018 average	0.09[10]
				Peak	<0.6
	Surface flow loss	Surface flow modelling and measurements	Waratah Rivulet, Eastern Tributary	Recent	0[11]
Wongawilli	Total mine water take	Total pumped out water	Wongawilli mine catchment	2014-2019 average	0.8[4,12]
Russell Vale	Total mine water take	Total pumped out water	Russell Vale mine catchment	2014-2019 average	1.8[4,12]

1. §4.2.2 Part 1 Report (18 GL in 8 years). 2. §3.4 and 4.5.1 Part 1 Report; South32 (2018a). 3. §4.5.1 Part 1 Report (6 GL in 8 years). 4. The upper limit estimate of current losses over the Dendrobium, Wongawilli and Russell Vales mines of an average of 8 ML/day is based on summing these values. 5. §4.5.1 Part 1 Report. 6. §4.2.3 Part 1 Report; HGEO (2017a). 7. §5.5 HydroSimulations (2018b). 8. Table 5-4 HydroSimulations (2018b). 9. §6.3 Part 1 Report; Section §5.2. 10. 20 day rolling average §3.3 Part 1 Report; Hebblewhite, Kalf, and McMahon (2017). 11. §6.2.2 Peabody (2018a). 12. Wollongong Coal (2019a).

3.2.4 Understanding variability of mine water takes and relation to mining parameters

Understanding the variability of mine water takes over time is central to estimating cumulative water losses. The following commentary and Table 4 highlight this variability and some of the complexities involved.

Whitfield (1985, 1986, 1988) reported on a stepped increase in the quantity of water being pumped from Wongawilli Mine during pillar extraction in Blue-2 and Blue-4 panels in late 1982. The panels were located on opposite sides of an arm of Avon Reservoir, close to the confluence of fours arms in an area affected by igneous sills and dykes and cindered coal. Depth of cover, H, ranged from 90 to 140 m and mining height was 3 m. The panels were located in the Restricted Zone, defined by the Dam Safety Committee (DSC) as a plan distance equivalent to 1.2 H from Full Storage Level (FSL), and abutted the Marginal Zone, defined as an equivalent distance of 0.7H (or 35^0) from FSL. The area in the immediate vicinity of both panels was geologically disturbed, with Blue-2 Panel being bounded by a sill and Blue-4 Panel being bounded by a sill and cindered coal and transected by a major dyke that was projected to extend under the reservoir. Total extraction took place up against one side of the dyke.

With the commencement of pillar extraction in Blue-4 Panel adjacent to a 2 m thick dyke in July 1982, water inflow increased from 0.14 to 0.29 ML/day and then to 0.7 ML/day on completion of extraction in September 1982. In December 1982, during extraction of pillars adjacent to the sill in the nearby Blue-2 Panel, water inflow increased dramatically from 0.67 ML/day to 2.4 ML/day. It then decreased to 1.9 ML/day and maintained that level for 9 months. Subsequently, Doyle & Poole (1986) reported that the flow had decreased to 1.1 ML/day by December 1985 and to 0.86 ML/day by May 1986. The Panel has been unable to source later figures other than very recent pumping records for Wongawilli Mine which show a peak average pumping rate of 3.1 ML/day in 2015/16 and a low of 1 ML/day in 2018/19. It is unknown if these figures represent all inflow into the mine.

Williamson (1984), Whitfield (1985, 1986, 1988) and Doyle and Poole (1986) report on the range of potential causes that were investigated. Water inflow from flooded old workings was dismissed as a cause, while algal analysis indicated that a large body of surface water, possibly from Avon Reservoir, was a direct or indirect source of at least a component of the water. Williamson (1984)[22] reported that although water inflow via Blue-4 Panel was gradually decreasing, its response to rainfall events with a time lag of only a few days suggested that its source was a groundwater system being rapidly recharged by rainfall. According to Doyle & Poole (1986), the chemical analysis of inflowing water had depicted little change over two years, indicating that the Blue Panel water originated neither from old workings nor Avon Reservoir. They contended that the water inflow was derived from natural groundwater in the Wongawilli Seam and surrounding strata. On the other hand, Whitfield (1988) stated that the increase in water inflow during extraction of Blue-4 panel suggests that the dyke was acting as a conduit for water, either directly or indirectly, from Avon Reservoir.

Further evidence of the variability of surface water takes between mines is shown in Table 4 for the following mines:

- experimental pillar extraction workings undertaken within the Marginal Zone of Cataract Reservoir and under the Cataract Reservoir at Bulli Colliery (Kapp & Kennerley, 1986; Whitfield, 1988)
- longwall workings undertaken under Cataract Reservoir at South Bulli Colliery[23] (Byrnes, 1999; Singh & Jakeman, 1999, 2001)
- longwall panels at Metropolitan Mine (Part 1 Report)
- longwall panels at Dendrobium Mine (Part 1 Report)

[22] As reported by Whitfield (1988)
[23] Now known as Russell Vale Mine

Table 4: Case studies of mining in the Southern Coalfield that have informed the review

Year	Mine (Method)	Panels	Depth of Cover, H (m)	Panel Width W (m)	W/H	Mining Height h, (m)	Inter-panel Pillar Width W_p (m)	W_p/H	W_p/W	Areal Ext.	Max Vertical Disp (Subsidence) V_z (S_{max}) mm	V_z/h	Predicted Height of Fracturing[7]	
													Ditton	Tammetta
c1980[1]	Bulli Colliery under Cataract Reservoir (Pillar Extraction – Wongawilli Method)	1SW	315	86	0.27	2.4	35	0.11	0.41	71%	35	1.5%	76 m 0.24H	57 m 0.18H
		2SW	310	79	0.25	2.4	45	0.15	0.57	64%	75	1.9%	72 m 0.23H	52 m 0.17H
		3SW	308	79	0.26	2.5	50	0.16	0.63	61%	105	2.0%	74 m 0.24H	55 m 0.18H
1993-1997[2]	South Bulli Mine under Cataract Reservoir (Longwall)	501-508	300 to 450	110	0.24 to 0.37	2.3 to 2.8	66	0.15 to 0.22	0.6	63%	180 .	7% to 9%	83 – 103m 0.28-0.23H (h=2.5)	76 – 82m 0.25-0.18H (h=2.5)
c2015 – present[3]	Metropolitan Mine (Longwall)	24-27 under land	400-500	163	0.33 - 0.41	2.8-2.9	40-47	0.08 to 0.12	0.26 to 0.29	78%	1170 - 1190	42%	119 – 134m 0.30–0.27H (h=2.8)	137 – 143m 0.34-0.29H (h=2.8)
		304-306 proposed under Woronora Reservoir	~400-540	138	0.26 - 0.35	2.7	70	0.13 to 0.18	0.51	66%	-	-	110 -129m 0.28-0.24H	111 – 118m 0.28-0.22H
c2005 – current[4]	Dendrobium Mine (Longwall)	Area 2[5]	138-310	245	0.79 - 1.78	3.75	45	0.16 to 0.33	0.18	84%	-	-	83 – 140m 0.60-0.45H	242 -281m 1.75-0.91H
		Area 3B[6]	273 - 409	305	0.75 – 1.1	3.4-4.6	45	0.11 to 0.17	0.15	87%	3500 - 3600	76% to 78%	146 – 182m 0.53-0.44H (h=3.95)	356 – 383m 1.30-0.94H (h=3.95)

1. Kapp and Kennerley (1986), Whitfield (1988), subsidence developed incrementally, 1SW terminated within Marginal Zone, 2SW and 3SW partially under Cataract Reservoir, water make did not exceed 1,120 L/hr (0.03 ML/day),
2.Byrnes (1999), Singh & Jakeman (1999; 2001), depth to floor of reservoir ~250 m, subsidence developed incrementally, Max Vz over LW 505, Water pumped out of area = ±30% of water piped to area from the surface, Water inflow from drippers and goaf too small to measure – abated to <0.5L/s, Piezometers investigations indicated zone of connected vertical fracturing extended to ~130m above the seam (based on significant loss of pressure head), Higher than 185m above the seam, there was no evidence of any change in hydraulic connectivity.
3. Subsidence develops incrementally, Extraction of LW 304 only recently commenced at time of compiling this report, 0.09 ML/day average water make from 2009 to 2017 which has remained relatively unchanged throughout this period and does not respond to rainfall.
4. As at 2018, total mine water inflow about 7.5 ML/day and includes components of lateral seepage from Avon Reservoir and Cordeaux Reservoir and responds to rainfall.
5. Generally agreed that this domain responds to rainfall. Analysis by MER (2016) concludes numerous events of inflow above 1 ML/d attributable to rainfall, with one event above 5 ML/d
6. Subsidence developed incrementally. Analysis by MER (2016) concludes that a reasonably strong correlation of mine inflow to rainfall can be inferred in this domain but with a discernible delay of a few days between some events. Peaks of 1 to 2 ML/day.
7. These values do not include allowance for error bands

Table 4 includes estimates of the height of complete drainage predicted by both the Ditton equation (DGS, 2013; 2014) and the Tammetta equation (Tammetta, 2013)[24] . It shows that for those mines which have undertaken or plan to undertake total extraction mining under reservoirs:

- excavation width-to-depth ratios, W/H, are low, falling in the range of 0.24 to 0.37;
- interpanel pillar width-to-excavation width ratios, W_p/W, are high, falling in the range of 0.51 to 0.63; and
- the Ditton and Tammetta equations produce similar values for height of complete drainage, H_d, above the mining horizon and this is low, falling in the range of 0.17 to 0.28 times the depth of mining (disregarding error bands).

These values contrast with those determined for Dendrobium Mine Areas 2 and 3B, which are outside the Marginal Zones of reservoirs, where:

- excavation width-to-depth ratios are high, and range from 0.75 to 1.78;
- interpanel pillar width-to-excavation width ratios are low, ranging from 0.15 to 0.18; and
- the height of complete drainage based on the Tammetta equation is 0.91 to 1.75 times the depth of mining.

Thus, the mining dimensions associated with total extraction panels in the Special Areas are towards a low (conservative) extreme when mining under reservoirs and towards an upper extreme when mining outside of the Marginal Zones of reservoirs at Dendrobium Mine.

3.3 ESTIMATING DEPRESSURISATION AND SURFACE WATER LOSSES USING GROUNDWATER AND SURFACE WATER MODELLING

Groundwater models and surface water models are used to improve understanding of ongoing water losses and to predict potential future water losses.

3.3.1 Groundwater modelling

The use of 3D groundwater flow modelling in the Southern Coalfields was first recommended by the SCI.[25] Since then there has been considerable development, evaluation and refinement of groundwater models for the Metropolitan and Dendrobium mines. These developments are summarised in the Part 1 Report.

The conceptual model in Figure 7 raises a number of issues in regard to modelling. In particular, the Panel notes from historical submissions for planning approvals that one of the most challenging aspects of modelling relates to the representation of the fractured subsidence zone above longwall panels where vertical and horizontal hydraulic conductivities are enhanced through cracks and bedding plane shears. This results in a dual porosity-dual permeability system where fracture flow is dominant within deeper parts of the zone while matrix flow may be retained in shallower parts of the subsidence zone unless fracturing extends to surface. The models employed for planning and impact assessments assume porous media flow throughout the flow domain with simplified representation of occasional fractures. Two model codes are currently favoured by industry. They are:

[24] Noting that the Panel has recommended erring on the side of caution and adopting the Tammetta Equation until either or neither are validated.
[25] SCI Report, p. 84

- Modflow Surfact which is a variant of the original Modflow finite difference code. This code employs a structured grid[26] to discretise the groundwater system and has been the preferred model platform for many years; and
- Modflow USG which is also a variant of the original Modflow code but offers an unstructured grid approach to discretisation of the flow system. This facilitates implementation of a finer mesh in areas of steep hydraulic gradients and a coarser mesh in areas of reduced interest. Ultimately this leads to shorter model simulation times when compared to a Modflow Surfact structured grid.

A notable difficulty in simulating the groundwater domain using these codes is the representation of the vertical displacement of the water table as the migrating subsidence wave front at the coal face traverses across the width of an individual longwall panel. This displacement at the surface (typically 1 to 3 m) is not simulated within the above noted model codes due to the complexities associated with instantaneous changes in porous storage. Hence impacts within the surficial zone (swamps and stream beds) that are predicted by modelling, are likely to retain a high level of uncertainty. Groundwater flows within the underlying strata (and within the subsidence zone) are generally simulated using one of the following methodologies:

- *Representation of the fracture network using one or two dimensional discrete feature elements.* A high level of uncertainty is considered to prevail since it is impossible to know the location, connectivity and hydraulic properties of the entire crack-fracture network
- *Calculation of approximate increases in model permeabilities (as equivalent porous media)* during data preparation, and changing cell properties during the simulation to initiate and accelerate vertical drainage. Coal extraction is represented by 'drain' nodes within the designated coal seam model layer. While this is generally the most popular approach to simulation of the subsidence zone, it can generate significant uncertainties associated with head predictions
- *Use of boundary conditions to represent vertical drainage within the subsidence zone.* This typically involves the assignment of 'stacked' drain nodes for Modflow codes. The progressive vertical drainage is determined by the conductance applied to a particular node which may be calculated according to specific cell conditions. Highest conductance is typically assigned to the extracted coal seam layer with reducing conductance assigned to nodes in overlying model layers. Using this approach, it is possible to initiate unnatural (and premature) dewatering of elevated parts of the subsidence zone rather than a progressive dewatering of strata from the seam panel upwards.

In all of the above methodologies it is necessary to establish the vertical extent of the interconnected fractures before undertaking simulations. If the height of fracturing does not extend to the surface then a groundwater model provides a means of estimating contributions (and losses) from porous storage in shallow strata, and subsequent impacts on the water table. Losses in base flows of drainage systems can also be estimated.

However, if the height of connected fracturing extends to the surface, any losses via fracture flow from surface to seam cannot be predicted by a groundwater model, mainly because it is impossible to identify individual fracture pathways and their hydraulic characteristics. Instead these contributions, which often correlate to rainfall-runoff events of relatively short duration, may be estimated from volumetric water balances conducted as part of underground operations.

[26] A structured grid or mesh is rectilinear with each layer extending across the entire model domain. An unstructured grid can be based on different cell shapes (rectangular, triangular, polygon) and may include layers that do not extend across the model domain.

3.3.2 Surface water modelling

Surface water models (rainfall-runoff models) have been used in the Special Areas since 2008 (LW 5, Dendrobium Mine). These models need to be calibrated using pre-mining stream flow data. The models are then used to simulate creek flows in post-mining periods where loss of flow is normally reflected in departure of the observed flow from the predicted (pre mining) flow. If the observed flow is consistently lower than the pre-mining flow and this cannot be explained by model or observation error, then flow losses due to mining are concluded.

Peer reviews have generally concluded that the surface water models are useful and are being employed in an appropriate way, while recognising inherent uncertainty and in some cases the need for better reporting of this uncertainty. The Panel agrees with these conclusions. It recommends that independent published peer reviews of the surface water models, associated data, and interpretations of results including reporting of uncertainty should be a more regular part of the assessment process.

In recent years the widely recognised Australian Water Balance Model (AWBM), and modifications of it, have been employed by both the Metropolitan and Dendrobium mines. Investment in flow monitoring since the SCI has permitted increased use of the AWBM model, which in 2019 is applied to seven sites on watercourses above and around Dendrobium Mine and two at Metropolitan Mine.

Several of these sites have less than two years of pre-mining data, contributing to the uncertainty in the model results. At least two years of baseline (pre-mining impacts) data are required, and ideally at least four years at sites that are strategically important in terms of monitoring water supply, and at control and performance measure sites. Flow can be modelled at sites with shorter observation records but uncertainty will be higher and less quantifiable. Decisions regarding new or upgraded flow gauges in the Special Areas should be made cautiously due to the difficulties and environmental impacts associated with construction and gauge maintenance. Continued communication between WaterNSW and the mining companies is necessary for informed selection of new and upgraded gauging locations.

3.3.3 Integration of groundwater and surface water models

Interactions between the groundwater and surface water systems are an important part of the flow loss mechanism, affecting the rate of drainage of surface water through fracture networks, loss of baseflow due to depressurisation and generation of baseflow due to repressurisation following mine closure. In principle, there would be benefit in integrating groundwater and surface water models, where they would be merged into one model or exchange information while running, to ensure predictions of flow losses fully consider these processes.

However, integration of surface water and groundwater models, is not practical for assessing the impacts of mining in the Special Areas. This is mainly due to the differences in time and space scales involved. Surface water models are required to model rapid changes of flows in response to rainfall events and to model flows at only one point in the catchment (the outlet gauge). On the other hand, groundwater models are not required to simulate rapid responses to rainfall, but are required to provide results at multiple nodes over the area and depth of the catchment. For these reasons, groundwater models and surface water models used in the Special Areas are not integrated, they do not necessarily give consistent flow loss results for historical periods, and there remains limited capability to predict future surface flow losses. Surface water models have in some cases been used to inform the recharge inputs to groundwater models.

Although integration of models is not practical, groundwater model calibration considers gauged observations of baseflow and modelled baseflow losses, notwithstanding that the value of these is limited by uncertainty in baseflow measurements (flow gauge accuracy) and by lack of observed baseflow profiles along the major watercourses.

3.3.4 Uncertainty analysis

Uncertainty analysis is considered an essential part of good practice for both groundwater modelling and surface water modelling. Its importance in assessing coal mining impacts in Australia is recognised by the Australian Government's Independent Expert Scientific Committee (IESC): *"there is a growing and widespread national and international recognition – across government, industry, research and academia – of the importance of uncertainty analysis in groundwater modelling and decision making"* (IESC, 2018). The same IESC document provides non-comprehensive guidance on conducting uncertainty analysis for groundwater models, developed around numerous previous sets of principles and guidance, including the Australian Groundwater Modelling Guidelines (Barnett et al., 2012).

More comprehensive guidance for specific uncertainty analysis approaches is available in the references cited. The IESC guidance is not prescriptive about methods, recognising that different modelling contexts will require different uncertainty approaches. The guidance advocates that a modelling workflow for uncertainty analysis should be followed and suggests such a workflow.[27]

The 3D groundwater modelling used for the Metropolitan and Dendrobium mines have generally followed the Australian Groundwater Modelling Guidelines of Barnett et al. (2012). This has included analysis of selected uncertainties. It has also included recognising the presence of uncertainties and assumptions, although not always with comment on how these may affect modelling outcomes. The submission from WaterNSW to the Panel considered that uncertainty analysis was a deficiency of the modelling currently being used to support mining applications. The agency commented that "*the assumptions in the models and uncertainties in results are not adequately disclosed or discussed in modelling reports, and the suitability and applicability of the chosen model needs to be justified"*.[28] The Panel agrees with this view. A more formalised and transparent uncertainty analysis workflow is required, consistent with the IESC guidelines.

Adopting the IESC guidelines may have implications for the approach to quantitative uncertainty analysis. These guidelines state: "*the proponent should conduct a quantitative uncertainty assessment to a level of detail commensurate with the potential risks and consequences of the project*". This requires careful consideration of achieving the suitable balance between model complexity and robustness of the quantitative uncertainty analysis (the complexity and computational burden of the current models may not permit the more comprehensive approaches to quantitative uncertainty analysis).

The principles and guidance in the IESC document are also relevant for surface water models, in particular, the modelling workflow for uncertainty analysis should also be applied to surface water models. However, the details of the approaches to uncertainty analysis are unlikely to be the same for surface water and groundwater models due to their different complexities and purposes. Specific guidance for rainfall-runoff models is available from other sources including eWater (Vaze et al., 2011). This guidance has been referred to in many of the mining companies surface water modelling reports, including recognition of uncertainty, but without applying a workflow that leads to clarity of decisions about what the uncertainties are and which should be quantified and how.

3.3.5 Regional scale and cumulative loss modelling

Extending models to estimating cumulative water losses over the Special Areas and to cover historical mining areas presents numerous challenges including:

[27] Figure 3 (p. 13), IESC (2018)
[28] Submission No.30, WaterNSW

- extending conceptual and numerical models to a more regional scale, including the expense and time required to develop and run groundwater models such as those used at the Dendrobium and Metropolitan mines over all areas potentially affected by historic, present and future mining
- mining in the Greater Sydney Water Catchment, including at both Metropolitan and Russell Vale mines, predates the establishment of the Special Areas[29] and currently insufficient information is available on factors that inform the quantitative assessment of cumulative impacts, both short term and long term. These factors include site-specific geology, mining dimensions, efficiency of extraction, surface subsidence magnitudes and profiles, monitoring of groundwater, surface water and swamps systems, and the state of mine rehabilitation and closure
- considerable uncertainty is still associated with estimating the relative contributions and magnitudes of the various potential sources of water inflow into mine workings
- information on spill points and water outflows relevant for post-closure predictions is not readily available and may not exist in many cases
- analysis of impacts, both short term and long term, is clouded by interaction and interconnections between workings both in the same and different seams in some mines, and between mines in different mining leases.

These challenges mean that wider regional scale modelling, covering all catchments in the Special Areas and historical mines, cannot reasonably use 3D groundwater models. In areas and periods covered by mining companies' 3D groundwater models, the surface losses predicted by those models can be employed with due regard to uncertainty. Losses calculated from measured mine water takes can also be employed. In areas of historical mining, due to the absence of alternative applicable modelling approaches, expert judgement based on general knowledge of how mines of different geometries interact with hydrogeology is likely to provide the best practicable estimates of losses, although this will be complicated by the need to consider interactions between mines. As the database on losses grows, research into alternative approaches, such as empirically relating losses to mining and hydrogeological variables, may result in a reasonable estimation of cumulative water losses over the Special Areas.

Therefore, due to the inherent difficulties, the Panel does not recommend development of a new regional scale model covering the Special Areas at least until the knowledge base is substantially developed, with regard to the challenges listed above. WaterNSW should use best available estimates of mining-induced losses in their Greater Sydney supply system model complemented by research into expert-based and/or simple empirical estimation methods.

3.4 WATER QUALITY

This section focusses on surface water quality in the context of potential consequences on Greater Sydney water supplies.

The SCI reported that water quality in watercourses is affected by numerous factors including runoff from swamps and interactions between bedrock and water, with fracturing of bedrock due to mining causing considerable local water quality consequences. The SCI report also raised the possibility for water quality degradation associated with undermining of swamps but noted a lack of evidence. The Panel is not aware of any monitoring to specifically assess any water quality consequences of swamp deterioration.

[29] Russell Vale Mine has been in continuous operation under various names since 1885, while mining activity has taken place in the area since 1858 (Byrnes, 1999). Mining operations at the Metropolitan Mine commenced in March 1886.

Since the SCI there has been intensive monitoring of surface water quality in the areas of the Dendrobium and Metropolitan mines. This has confirmed the widespread presence in some watercourses of iron, resulting in iron staining and in some cases bacterially-mediated iron matting, and other geologically sourced contaminants associated with fracturing. Reduction in iron staining and iron matting (where fracturing of the base of watercourses is limited to the near surface and does not connect to deeper subsurface fracture networks) is expected over time due to flushing during high flows and exhaustion of the source of iron, although the time-scales are variable.

The 2016 literature review prepared for WaterNSW indicated that mining is not currently having significant consequences for water supplies. Advisian (2016) concluded:

> "*In summary, although some consequences on water quality within the watercourses in the study are documented in the literature, these consequences are likely to be short term, sporadic and localised… Any consequences on water quality at the reservoirs would be treatable by the existing Sydney Water treatment plants."*

However, the literature review did not consider potential consequences of groundwater outflows from spill points following mine closure and groundwater repressurisation. This needs careful consideration because of the potential for the outflow to leach metals as it travels through the overburden fracture network. The total surface area of fractures in this network is orders of magnitude greater than that of local fracture networks that affect water quality in watercourses impacted by valley closure. This could have serious potential implications for both the volume of metals reporting to the Sydney water supply in the future and for the unknown but likely extremely long duration of these elevated metal loads, unless appropriately managed. As management options may be limited where spill points occur inside Special Areas, considerations arise as to whether it is feasible to restore water table in the long term.

Better understanding of the potential long-term contaminant loads to reservoirs and other water supply works is essential. This should include integrating monitoring of contaminant concentrations with flow monitoring at operational mines so that contaminant loads can be calculated and modelled at key locations. Relevant contaminants should be agreed between primary stakeholders.

3.5 SIGNIFICANCE OF SURFACE WATER LOSSES FOR GREATER SYDNEY WATER SUPPLY

The losses referred to in Section 3.2.3 are low compared to other components of Sydney's supply and demand, for example recent losses from the Dendrobium, Russell Vale and Wongawilli mines of less than 8 ML/day on average compare to the Sydney Desalination Plant capacity of approximately 250 ML/day (Sydney Desalination Plant, 2019) and estimated leaks from the Sydney Water supply infrastructure of approximately 130 ML/day (Sydney Water, 2018).

Comparisons of mining-induced losses with unmanageable components of the supply system's water balance should be avoided. For example, comparisons by some stakeholders with evaporation from storages is not helpful since reducing evaporation on the spatial scales required is not a realistic water efficiency option.

The significance of different levels of loss in terms of reductions in system yield and necessary compensatory investments or other management actions is unknown. The system yield of the Sydney water supply system is *the average annual demand for water that can be sustainably met over the long term*. It is calculated by increasing the water demand in the Greater Sydney supply system model until one of three criteria is not met: a reliability criterion, a robustness criterion and a security criterion. The security criterion is the most relevant in the context of assessing the potential consequences of mining for water supply. It is that storage should not fall below 5% of storage capacity in more than one in every

100,000 months (WaterNSW, 2018). The water demand at this point is called the security yield. Modelled system yield and security yield depend on scenarios of infrastructure and operating rules, among other model inputs.

Assessment of the significance and tolerability of cumulative water supply losses due to mining should be based primarily on the degree to which they reduce security yield, including consideration of whether the reduction would require compensatory investments or other management actions. WaterNSW presented to the Panel the initial stages of work towards a framework that will support this assessment. Predicted water losses used in this assessment should be conservatively high, ideally with stated probabilities of non-exceedance, to allow for prediction uncertainty.

In 2008, the DSC derived a tolerable reservoir storage loss limit of 1 ML/day for use in assessing applications to undertake mining within a DSC Notification Area (DSC, 2019). The limit originates from analysis of the significance of losses from Cordeaux Reservoir which concluded that any sustained loss equal to or lower than 1 ML/day was a tolerable loss relative to the reservoirs' security yield at that time (predicted losses of higher than this were considered tolerable if the likelihood was considered to be very low). With no better estimate method, the 1 ML/day limit has since been adopted for other reservoirs and continues to be referenced as a relevant tolerable loss limit for individual reservoirs. The DSC submission to the Panel notes that the 1 ML/day tolerable loss will restrict future proposed longwall extraction around Avon Reservoir (DSC, 2019). The Panel has not heard any evidence that 1 ML/day is connected to present-day estimates of security yield of the Greater Sydney water supply system.

Developing an objective and up-to-date tolerable loss for individual reservoirs needs to have regard to tolerable cumulative losses from the Special Areas and account for current and possible future losses from all reservoirs. The submission to the Panel from WaterNSW recommended creation of an interagency taskforce to establish thresholds for catchment water loss.[30] The Panel agrees with this approach. Thresholds for the Special Areas and new thresholds for individual reservoirs should be established by the taskforce.

The potential impact of climate change on Greater Sydney's water supply is relevant to assessing the significance of water losses. Reasons for this include: 1) the losses due to mining depend on the hydrological status of the catchments, which depends on climate; 2) tolerable losses might be different under a changed climate; 3) if the uncertainty in security yield due to climate uncertainty is much larger than that due to water losses arising from mining, low accuracy estimates of the latter may be sufficient; 4) changes in temperature may affect water quality risks.

The 2016 Independent Review of the Greater Sydney's water supply system yield model (WATHNET5; WREMA, 2016) made recommendations for improving the yield methodology by improved stochastic methods for modelling long-term climate variability, and further investigations into suitable methods and data sets for climate change impacts analysis. This type of improvement is essential in order to understand the significance of water losses due to mining and how much their uncertainty contributes to overall uncertainty in future security yield.

3.6 MANAGEMENT OPTIONS

3.6.1 Applicability of TARPs to surface flow losses

The TARPs for Metropolitan, Dendrobium, Wongawilli and Russell Vale mines are based on three or more flow loss trigger levels. The levels are defined by thresholds of flow losses relative to baseline flows. The thresholds and how they are defined vary between mines. At Wongawilli and Russell Vale mines, the thresholds are related to surface flow conditions that

[30] Submission No.30, WaterNSW

are ‘normal’, ‘within predictions’ and ‘exceeding predictions’. At the Dendrobium mine, in addition to three TARP levels defined by flow losses relative to rainfall, the performance measure site (WWL) has a specific ‘exceeding predictions’ TARP that is not applicable to the other sites. The flow loss TARPs are assessed by comparing rainfall-runoff model results that represent unimpacted conditions to observed flows. In some cases, this is supplemented by comparisons of observed flows at the TARP site with those at control sites.

At the Metropolitan Mine, although there have been no reported triggers at the flow loss TARP site, there have been triggers of the pool level TARPs on both the Eastern Tributary and Waratah Rivulets. For Waratah Rivulet this has resulted in remediation of cracks in rockbars by grouting which, in terms of restoring pools, has been successful. Similar remedial action is planned on the Eastern Tributary.

At the Dendrobium Mine, there have been flow loss TARPs on a tributary of Wongawilli Creek (WC21), Donalds Castle Creek and a tributary of Lake Avon. At WC21 and Donalds Castle Creek, there is a plan to remediate some pools with grouting, recognising that this aims to restore surface runoff but not baseflows. Loss of baseflow input to the watercourse is due to groundwater depressurisation, which cannot be addressed by sealing surface cracks (South32, 2017c). At the Dendrobium Mine, there has also been a level 3 trigger due to low pool water levels (Pool 43a) coinciding with an observed crack in the bed of Wongawilli Creek. In this case, the trigger led to additional assessment, following which the mining company concluded that the low water levels and flows may be due to groundwater depressurisation (South32, 2018c). These examples from Dendrobium Mine show how a TARP has aided in detecting and reporting low pool levels and local loss of flow, and in the case of WC21 and Donalds Castle Creek activating a remediation procedure; however they also show that the TARPs, apart from a reporting function and trigger for remediation, do not contribute to managing flow loss due to groundwater depressurisation.

For the Dendrobium and Metropolitan mines, technical issues impacting the effectiveness of the flow TARPs are reviewed in the Part 1 Report. These include the relevance of the selected trigger levels, the completeness and transparency of the data analysis, and the period and accuracy of flow observations.

A further issue relates to timeliness of the TARP process. Following detection of flow losses, if remediation work is required, this may involve a delay of months to years while necessary investigations are undertaken and permissions granted, as well as waiting until incremental subsidence has ceased so that there is no post-remediation cracking. Therefore, there can be delays of months to years between onset of flow loss and remediation. However, where the TARP process contributes to reducing long-term flow losses, then such a delay may be considered acceptable.

3.6.2 Height of fracturing

Given the inherent uncertainty of predicting and estimating the magnitude of stream flow losses to fracture networks and the potential long term implications of fracture networks for water quantity and, in particular, water quality in the Greater Sydney water catchment, the Panel considers that it would be wise to adopt a precautionary approach and base mine design on preventing the height of free drainage in the Special Areas from extending to the surface or interacting with surface fracture networks. This does not necessarily mean that mining dimensions have to be as conservative as those that apply to mining under reservoirs.

The approach does not eliminate the risk of surface water and swamps continuing to be impacted by conventional and non-conventional subsidence, although it is likely to result in a reduction in the scale of many of these impacts. Furthermore, irrespective of whether the height of free drainage is permitted to extend to the surface, the issue remains of whether it will be feasible to effectively seal all defunct mines in the Special Areas. Further studies are required into the scale and technical aspects of this matter, which may not be confined only to mines that have or are working in the Special Areas. Factors such as hydraulic connections between mines, differential pressure heads between flooded mines and regional depressurisation might also result in mines external to the water catchment also influencing cumulative impacts within it.

It has been suggested that a beneficial solution is for sealed mines to continue to discharge water from mine entries and to treat this water to a standard sufficient to enable it to replace water that would otherwise be supplied from the catchment. Further investigation is required into how this option or alternate approaches could be factored into closure planning if it needs to funded and maintained in perpetuity.

3.7 CONCLUSIONS

a. The performance measures applied to the Dendrobium Mine do not sufficiently manage risks of surface water losses due to depressurisation. This is due to past limitations in knowledge about height of fracturing and potential cumulative impacts on pool levels and surface water losses.

b. Flow loss TARPs have been used with some success to incrementally detect and report flow losses, and to identify candidate sites for watercourse remediation.

c. In terms of general approach, flow loss TARPs are applied consistently across the four mines; however, there are significant variations in the details of how triggers are defined and assessed. There is no clear reason for these variations.

d. Confidence in flow loss TARP assessments could be increased by addressing key technical issues (see Part 1 Report).

e. The necessary delays between impacts and remedial action mean that outcomes from the TARP process may be months to years following on-set of local flow losses; however, this itself is not necessarily preclusive to effective use of TARPs for management of flow losses.

f. Although TARPs have been / are being applied to watercourse remediation and recovery of pool levels, as currently used they do not contribute to avoiding permanent flow losses due to groundwater depressurisation.

g. A considerable reduction in short term and long term environmental impacts may be realised by preventing the height of free drainage in the Special Areas from intersecting the surface either directly or indirectly by interaction with surface fracture networks.

h. This may be achievable beyond the Marginal Zones around reservoirs by working to mining dimensions that are not as conservative as those that apply to mining under the reservoirs.

i. Preventing the height of free drainage from reaching the surface does not eliminate the risk of surface water and swamps continuing to be impacted by conventional and non-conventional subsidence but it is likely to result in a reduction in the scale of many of these impacts.

j. The long term nature of cumulative impacts and their consequences for water quantity, water quality and swamp ecology in the catchment after mine closure have received limited attention in past mining proposals.

k. Following mine closure, the issues expand to include not only natural water inflow from the surface to mine workings but also the potential for water to outflow from the mine voids and fracture networks back to the surface as the mine fills, the quantity and quality of this outflow, whether it can report back into the catchment, and the consequences for water quantity and quality in the catchment if it does.

l. Much depends on whether it is physically possible to confine water in the mine and the extent to which the water table can be reestablished in order to reverse depressurisation.

m. Options for best managing cumulative impacts on water quantity and quality in the long term may include not attempting to restore the water table in defunct mines but, instead, allowing water to discharge from mine entries and treating it to a standard sufficient for it to replace water that would otherwise be supplied from the catchment. Further investigation is required into how this option could be factored into closure planning if it needs to be funded and maintained in perpetuity.

n. There is an increasing body of evidence that mining in the Metropolitan Special Area has resulted and continues to result in losses of water from the Greater Sydney water supply system. The losses include surface water diversions into the mines, leakage from reservoirs into the mines and loss of baseflow in watercourses due to groundwater depressurisation. Presenting a definitive recent loss rate for the Metropolitan Special Area is complex because the available estimates correspond to different time periods and/or catchment areas, and no estimates are available for most historical mines.

o. Available estimates show that the upper limit of recent loss rate totalled over the Dendrobium, Wongawilli and Russell Vale mines is an average of 8 ML/day and for the Dendrobium Mine alone is less than 5 ML/day. Loss rates from both Dendrobium and Metropolitan mines are expected to increase as the area of excavated coal seams increase. Loss rates at Dendrobium Mine vary over time depending on rainfall.

p. These losses are low compared to other components of Greater Sydney's supply and demand. For example, 8 ML/day compares to the Sydney Desalination Plant capacity of approximately 250 ML/day and estimated leaks from the Greater Sydney supply infrastructure of approximately 130 ML/day.

q. Losses of water from the Woronora Special Area due to mining impacts associated with Metropolitan Mine are negligible, with a water make between 2009 and 2017 that has averaged at 0.09 ML/day and, with the exception of May 2011, a 20 day average water make below 0.5 ML/day.

r. However, the significance of different levels of loss in terms of reductions in security yield of the Greater Sydney water supply system and necessary compensatory investments or other management actions are unknown. WaterNSW is developing an approach to address this.

s. The DSC derived a tolerable reservoir storage loss limit of 1 ML/day for use in assessing applications to undertake mining within a DSC Notification Area. The recent attempts to apply this limit for other purposes, such as cumulative losses, have no clear and up-to-date objective basis. The submission to the Panel from WaterNSW recommended creation of an interagency taskforce to establish thresholds for catchment water loss. The Panel agrees with this.

t. It is simply not feasible in current circumstances for the Panel to reasonably reliably quantify long term cumulative impacts of past and current mining operations on water quantity in the catchment.

u. In order to assess and at least qualify long term cumulative impacts of mining on water quantity and quality in the Special Areas, there is a need to establish the state of rehabilitation and closure of mines in and adjacent to the catchment, with a focus on the current quantity, quality and location of water outflow from each mine; the state of sealing of each mine; and the long term implications of mine sealing, including causing water to be diverted into adjacent mines as water levels rise within a sealed mine and to surface locations through fracture networks that daylight.

v. Considerable progress has been made in implementing groundwater and surface water models to help quantify water losses from the catchments affected by the Metropolitan and Dendrobium mines. Further refinements to groundwater models are necessary to improve accuracy.

w. The Panel does not recommend development of a new regional scale model covering the Special Areas at least until the knowledge base is substantially developed, having regard to the challenges identified in this Report.

3.8 RECOMMENDATIONS

7. All future mine approvals should include performance measures that are objective and can more precisely determine the cumulative impacts and consequences of a mine project progression. Performance measures should include changes in pressure and/or pressure gradients where these have the potential to impact on surface water losses.
8. When consent conditions make provision for meeting the requirements of performance measures by either by avoidance, mitigation or remediation, they need to be quite specific about the scope of attributes that have to be avoided, mitigated or remediated and the verification standards that avoidance, mitigation and remediation measures have to satisfy.
9. TARP triggers for surface and groundwater should be based on meaningful indicators developed in consultation with relevant agencies and authorities with oversight and regulatory responsibilities for mining
10. Uncertainty analysis of groundwater and surface water models should follow the uncertainty analysis workflow recommended by the IESC.
11. Independent expert peer review should become a more regular part of the groundwater and surface water model assessment process.
12. WaterNSW should continue its program of work towards determining the significance for the Greater Sydney water supply of different thresholds of surface water loss due to mining.
13. An inter-agency working group should be set up with the task of identifying acceptable levels of surface water loss due to mining.
14. A precautionary approach to mine design in the Special Areas should be taken that does not assume groundwater model outputs are accurate. Predictions of water losses should be conservatively high to allow for prediction uncertainty and where practicable the associated non-exceedance probability should be stated.
15. Additional flow gauges and improvements to existing flow gauges should continue to be undertaken selectively by mining companies in consultation with WaterNSW, or by WaterNSW (with potential financing from the companies) including aiming for at least 4 years of baseline flow data at sites that are important for quantifying water supplies including future performance measure sites and control sites.
16. Monitoring of contaminant concentrations should be integrated with flow monitoring at operational mines to support calculation of contaminant loads at the main inputs to reservoirs and other key locations and to improve understanding of future contaminant loading risks. Relevant contaminants should be agreed between primary stakeholders.
17. Government should ensure that sufficient water entitlements are retained by mines operating in the Special Areas to cover surface water losses resulting from mining-induced effects.

4 SWAMPS

The Panel's Terms of Reference include that it have a particular focus on the environmental consequences of mining for swamps. The Panel has addressed this by firstly considering mining impacts on swamp hydrology and then the ecological consequences that arise from these impacts.

4.1 BACKGROUND

The SCI concluded that, at that point in time, there was *"no scientific consensus over the role that mining subsidence may play in impacting swamps"*. It noted that it was clear however that subsidence impacts *"do have potential consequences for swamps"* and that *"no unaffected or 'healthy' valley infill swamps were observed where longwall extraction had taken place beneath them".*

The SCI also concluded that *"on the evidence available, it would appear that there is a distinct possibility that undermining of valley infill swamps has or will cause drainage, water table drop and consequent degradation to swamp water quality and associated vegetation".* It identified a need for further research to understand these potential impacts and to differentiate the effects of mining from other non-mining impacts such as bushfire and climate cycles.

Since 2008, a substantial body of research and the collection of monitoring data has improved understanding of the impacts and consequences of longwall mining activity, with several major reports reviewing these findings (Commonwealth of Australia, 2014c, 2014a, 2014b; DPE, 2015; Advisian, 2016).

Further, the ecological value of upland swamps has been recognised by their listing under both NSW legislation (in 2012 as Endangered Ecological Communities) and under Commonwealth legislation (in 2014 as Threatened Ecological Communities) and from the declaration of Dharawal National Park in response to known impacts on the swamps (Young, 2017).

In its Part 1 Report, the Panel concluded that it remains the case that there is no strong evidence of consequences of swamp impacts on catchment-scale water supplies. Uncertainty still surrounds the contribution that swamps make to baseflow. However, valley-infill swamps are likely to make a greater contribution than headwater swamps, because of the larger volume and water-holding capacity of their sediments.

Since the SCI, it has been established that longwall mining directly under swamps (both valley-infill and headwater) in the Southern Coalfield has resulted in changes to swamp hydrology. These changes have ranged from negligible to very significant. Swamps located several hundred metres from longwall mining panels may also be impacted.

Further investigations are required to quantify the nature of these impacts and their consequences for direction of surface runoff and ecology. However, the Panel is of the view that the impacts on hydrology and ecology are very likely to be irreversible.

4.2 HYDROLOGICAL IMPACTS

The location and regional distribution of swamps is strongly correlated with local hydrology and climate. The Illawarra Escarpment produces local climatic conditions conducive to the development of swamps, including orographic rainfall fogs and enhanced cloud cover. The climate combined with local topographic conditions (gentle slopes and poorly permeable sandstone substrate) promotes water-logging and swamp development (NSW Threatened Species Scientific Committee, 2012). The eastern portion of the Woronora Plateau shows the greatest development of upland swamps and "*represents the greatest extent and one of the oldest recorded occurrences of upland wetlands on the Australian mainland*" (NSW Threatened Species Scientific Committee, 2012).

At the time of the SCI Report, the hydrologic properties of the upland swamps were poorly understood. Since then, there have been significant advances in the understanding of upland swamp hydrology. This has been gained from the considerable monitoring (e.g. piezometers) that has been undertaken by the mines, as well as from other independent research.

4.2.1 Groundwater

Under natural conditions, the swamps store water from rainfall, runoff, groundwater and interflow[31]. After rainfall, this water may drain into the underlying sandstone if there is a downward hydraulic gradient, or flow horizontally through the swamp sediments or over the surface to provide downstream flow in the exit stream, or be lost by evapotranspiration.

The water table represents the depth below which the swamp sediment is saturated. In an undisturbed swamp where there is significant groundwater input to the sediments, the water table remains close to the swamp surface throughout long dry periods. Above this depth, in the unsaturated zone near the ground surface, the soil moisture[32] can vary between very dry and very wet. In swamps where rainfall is the dominant water source, slow recession of the water table indicates loss by evapotranspiration and outflow to streams (Evans & Peck, 2014; Cowley et al., 2019). After undermining of one swamp, Krogh (2015) documented falls in water table and soil moisture levels, and a median outflow of zero. This contrasted with a nearby control swamp of approximately half the catchment size but with median outflow of 13.5 kL/day.

Changes in water table position within the sediments are monitored by piezometers. The most extensive monitoring array within swamps in the Southern Coalfield is above Dendrobium Mine. In reviewing this suite of piezometric data, Sullivan and Swarbrick (2017) concluded that in undisturbed swamps, the hydrographic patterns matched peak rainfalls and long-term rainfall trends, at least for the period 2003-2012 for which the data was available. They found that nearly all piezometers in Areas 2, 3A and 3B (to that time) became dry after mining and thereafter displayed variable response to rainfall.

In situations where the groundwater in the sandstone lying directly underneath a swamp is depressurised due to mining, and/or where cracks in the sandstone develop that connect to deeper flow pathways, the vertical drainage from the swamp into the sandstone will accelerate. This is likely to reduce horizontal flow within the swamps towards the swamp outlet; although the increased vertical flow may move through bedrock and express as surface flow further down the watercourse.

Figure 9A illustrates this water table behaviour before and after mining for Swamp 05[33] at Dendrobium Mine. This behaviour is contrasted in Figure 9B with that of Swamp 02[34], which is a comparable swamp that has not been undermined.[35] A map of swamps in Areas 3B and 3C at Dendrobium Mine is at Figure 10. Prior to undermining of Swamp 05, the water table in both swamps was usually close to the ground surface and fell slowly in times of low rainfall. It generally did not fall to the base of the swamp sediments. Post-undermining, however, the piezometric traces for Swamp 05 show a change from a permanent water table within the swamp (as is common where a swamp is supported by groundwater from the adjacent

[31] Interflow is the flow entering the swamp sedimentary mass from the bedrock valley in which the swamp sediments lie, usually along bedding planes in the sandstone
[32] 'Soil moisture' in this context is the same as 'sediment moisture'
[33] Swamp 05 is classified as valley-infill. Swamp classification is complex in that swamps may exhibit characteristics of headwater and valley-infill swamps, an observation relevant to Swamp 05.
[34] Swamp 02 is located 1 km downstream of Swamp 05 and 800 m outside the Dendrobium Mine Area 3B mining domain. Sediment depth is 1.5 m compared with 2.5 m in Swamp 05.
[35] It should be noted that Swamp 02 has been previously impacted due to loss of water upstream. Swamps 01a, 01b, and 05 provided water to Donalds Castle Creek that feeds into Swamp 02, but his has largely disappeared. (Krogh, 2019)

bedrock) to one that is only intermittently within the swamp in response to rainfall (indicated by the cumulative rainfall residual, CRR[36]) and which falls abruptly once rainfall stops.

Similar piezometric changes to those shown in Figure 9A have also been observed at Swamp 8 on watercourse WC21, a tributary of Wongawilli Creek over Area 3B at Dendrobium Mine.

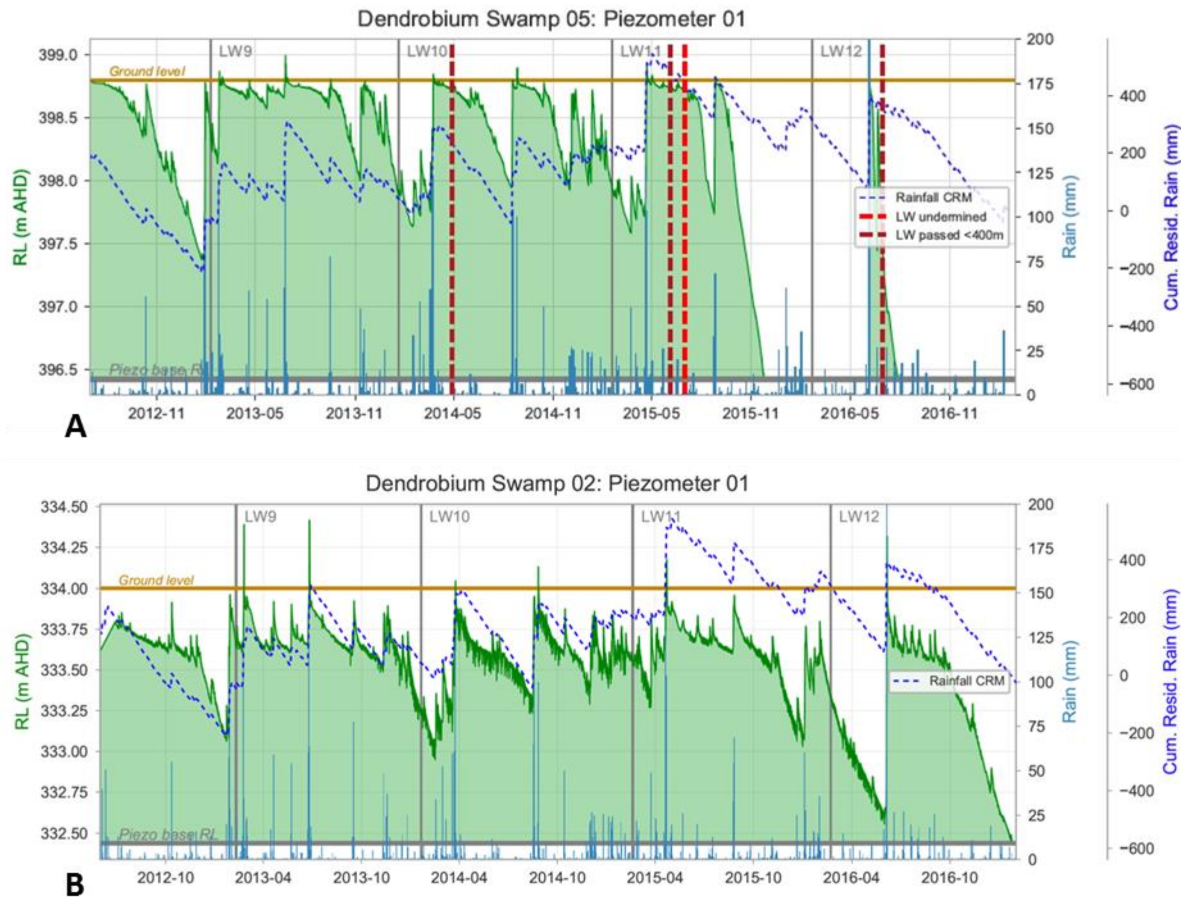

Figure 9: Hydrographs from A) Swamp 05 and B) Swamp 02 - Dendrobium Mine Area 3B
Source: HGEO (2017b)

[36] The CRR measures deviation from the average rainfall so that a rising graph indicates increasing rainfall and a declining trace indicates lower rainfall conditions

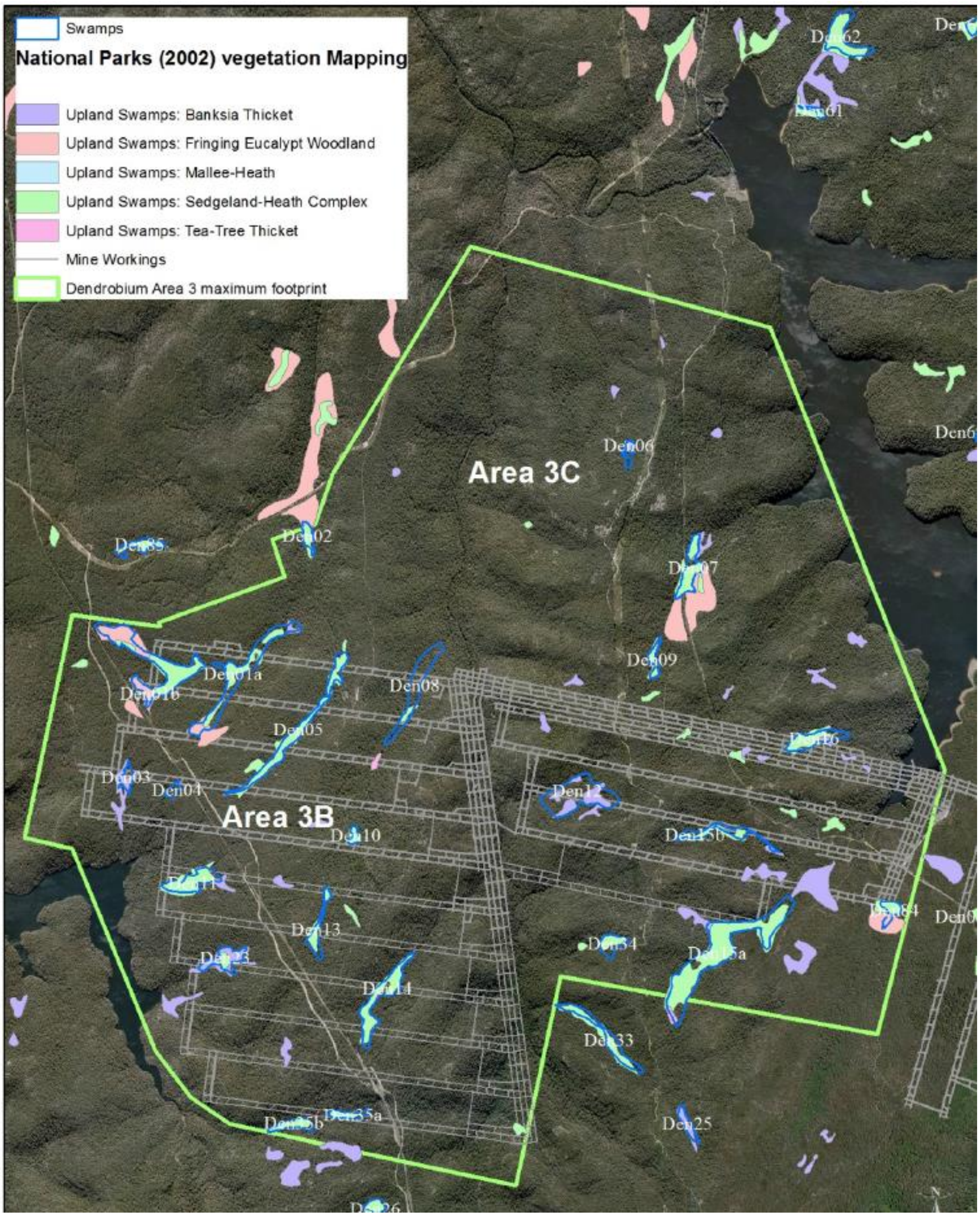

Figure 10: Location of swamps in Areas 3B and 3C - Dendrobium Mine
Modified from South32 (2016)

At the time of the MCP PAC most known impacted swamps were valley infill swamps, with only one example of an impacted headwater swamp at Dendrobium Mine. The MCP EA considered the swamps in the Metropolitan Project Area to be typical headwater swamps, and predicted negligible impacts to upland swamps. [37] The swamp classification[38] and impact prediction was questioned by the MPC PAC in that *"the EA essentially relies on the proposition that headwater swamps are generally subject to minimal valley related upsidence and closure movements and that the swamps in the project area are all headwater swamps".*[39]

[37] *"Given that negligible environmental impact to upland swamps was predicted for the original Project, negligible environmental impact would be expected in the case of upland swamps for the Preferred Project"* (Peabody Energy, 2009).
[38] *"The Panel raised with the Proponent on several occasions the issue of the accuracy of the claim that all swamps were headwater swamps. On each occasion, the Panel received strong assurances that the swamps are headwater swamps, e.g. 'there is no evidence to suggest that upland swamps within the Project Area are composite or transitional in nature'."* p. 85
[39] MCP PAC p. 84.

Subsequently, changes in water table levels have occurred at Swamps 20 and 28 at Metropolitan Mine (Figure 11). The Peabody submission notes that other swamps at Metropolitan Mine that have been undermined *"have not shown any mining effect"* and have *"responded similarly"* to control swamps.[40] The MCP Preferred Project Plan noted the relatively high closure strains predicted for a number of swamps, including Swamp 20, and the MPC PAC noted that these *"predicted closure strains would be sufficient to cause substantial impacts at these swamps"*.

Swamp 20 lies over the centre of LW 21, which was extracted in 2012. Thereafter, substrate in Swamp 20 changed from being permanently saturated to being periodically saturated (Peabody, 2019a). These changes are reflected in Figure 12, which records these significant falls in the water pressures not only near the swamp surface (1 m deep piezometer) but also in the underlying bedrock (4 m and 10 m deep piezometers) (HydroSimulations, 2019). Swamp 28 lies about midway between the centre and the maingate edge (side) of LW 24 and has shown an impact from mining since 2016 (Peabody, 2019a).

The Metropolitan Mine 2018 Annual Review Report comments that:

> *"While the water lost from Swamp 20 and Swamp 28 was retained in the unsaturated sandstone above the regional water table, the changes in swamp water levels as a result of cracking are measurable when compared to seasonal individual rainfall event based changes in swamp groundwater levels. There is currently no sign that the vegetation in Swamp 20 is being impacted by the changed hydrological conditions, however, the vegetation monitoring results suggest that the changes in vegetation occurring in Swamp 28 have been significantly different to changes in the control swamps since autumn 2017."*

The Panel notes that at Metropolitan Mine all swamps undermined to date are small and many lie over pillars and that impacts are very likely to be confined to the near surface with most, if not all, redirected flow returning to the surface and flowing into Woronora Reservoir. On the other hand, the Panel cannot rule out the possibility that a significant amount of the water that would normally flow into and out of Swamp 05 (and some other impacted swamps) at Dendrobium Mine is not being redirected into the mine workings or other catchments through the subsurface fracture network.

[40] Submission No. 26, Peabody

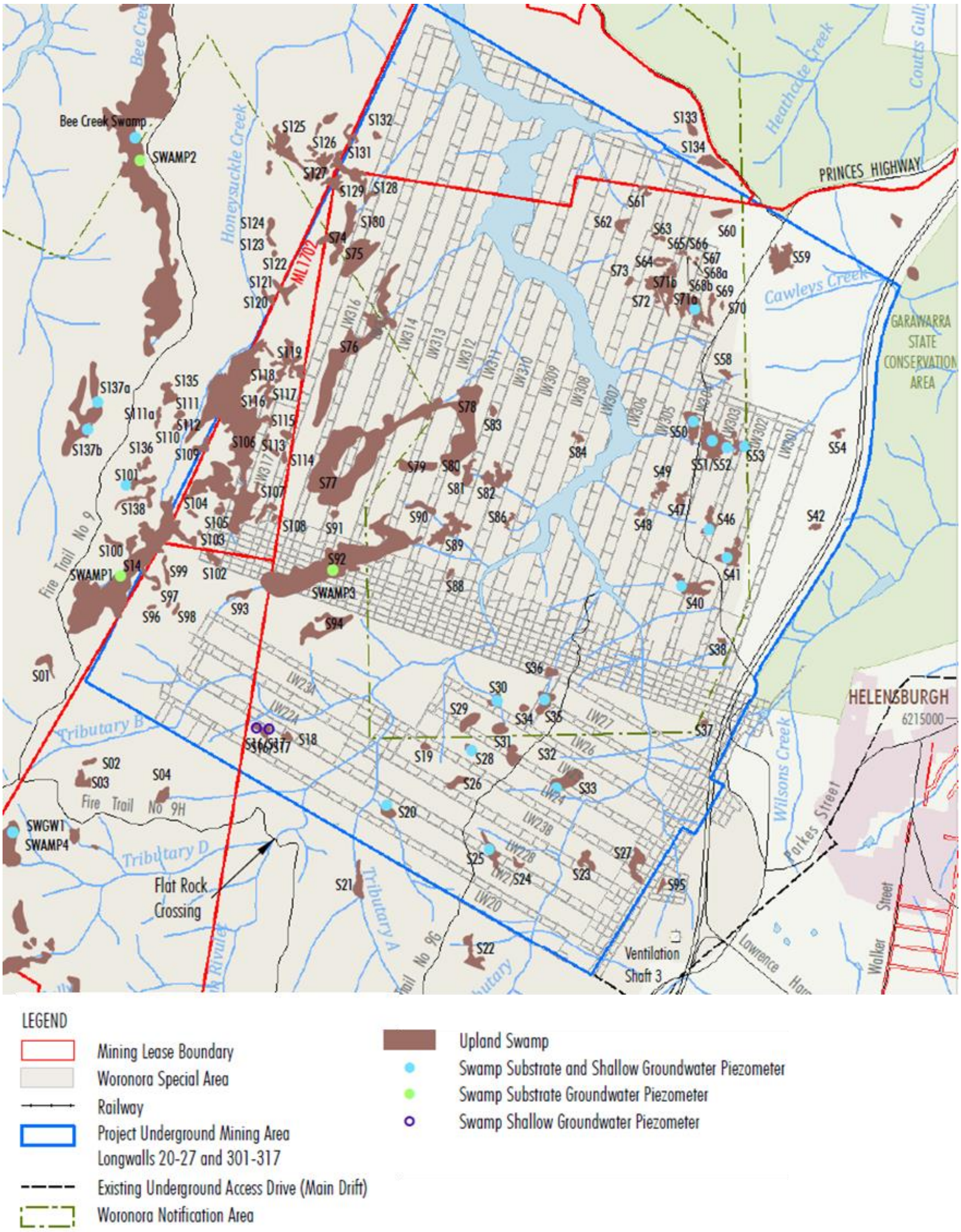

Figure 11: Upland swamp locations at Metropolitan Mine
Modified from: Figure 9, Peabody (2019a)

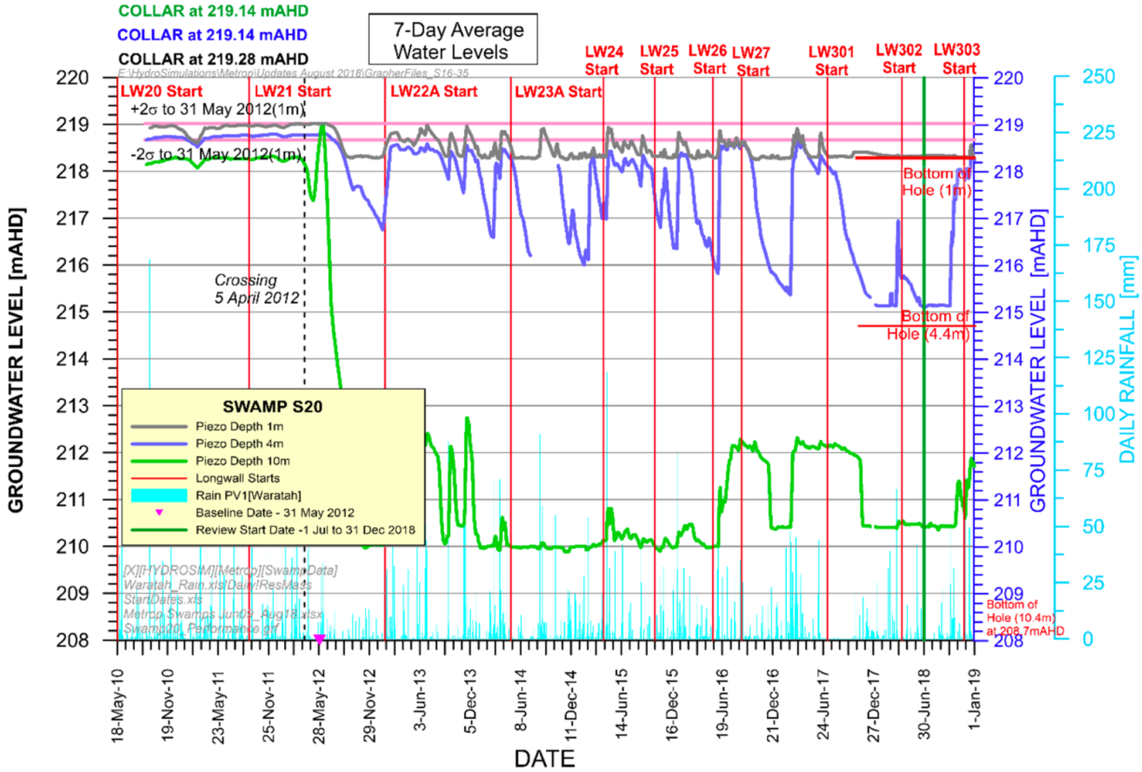

Figure 12: Swamp 20 groundwater hydrograph - Metropolitan Mine
Source: HydroSimulations (2019)

The available groundwater models are not applicable to reliably predicting mining impacts on swamps. Groundwater models do not have the capacity to unambiguously simulated the shallow and perched systems in the swamps. Material properties and flow balances of these systems are difficult to quantify and the level of discretisation required to represent them (cell size and layer thickness) is not generally compatible with a regional scale groundwater flow model.[41]

4.2.2 Soil moisture

Soil moisture content is important since it is a strong indicator of:

- water available for vegetation
- water deficit prior to surface runoff and baseflow being generated
- capacity of the swamp to accumulate and retain organic carbon content, and
- resilience to erosion and fires.

The variability of soil moisture in the unsaturated zone varies naturally with depth and sediment characteristics, as well as climate and the type of plants present. In the surficial (near-surface) sediments with much partly-decayed coarse organic matter, evapotranspiration is generally high, hydraulic conductivity is high, bulk density is low; and soil moisture declines quickly during low rainfall periods (Fryirs, Gough, & Hose, 2014). Deeper in the profile, the change in soil moisture is slower and more dependent on the sediment characteristics. Denser sediments high in organic matter are saturated under natural conditions and have hydraulic conductivities 10-1,000 times less than the fibric[42] surface material. However, near the base of many swamps, the sediments are coarser, being mainly sands and gravels, and flow through these is rapid. These features of swamps

[41] The challenges associated with integrating groundwater modelling with surface water modelling are discussed in §3.3.3
[42] The top layer of the sediments with fragments of decayed plant material

mean that, while piezometer levels give clear early evidence of hydrological change in response to mining, the consequences for ecology and hydrology are more complicated and require complementary soil moisture data at multiple depths.

An example at Dendrobium Mine of how changes in soil moisture content of a swamp correspond with a drop in its water table is shown in Figure 13 As the piezometric levels decline, so do the soil moisture levels. Changes are greatest at shallow depths and minimal near the sediment base, and there is a time lag between the lowering of the water table and the loss of soil moisture.

The possible impacts of the drying of swamps due to mining-induced changes in hydrology include:

- reduction of soil moisture levels and loss of cohesiveness of the swamp sediments
- enhanced risk of channelization and consequent susceptibility to erosion of swamp sediments, with potential water quality implications
- decline of groundwater-dependent plant species and consequent changes in vegetation structure
- decline of groundwater-dependent fauna including macroinvertebrates and stygofauna
- oxidation of peaty sediments resulting in increased hydrophobicity, lower water-holding capacity and potential changes in nutrient status and cycling
- increased risk of erosion, which may lead to gully formation.
- swamps have less resilience to bushfires which, in turn, can lead to an increased susceptibility to erosion and loss of baseflow (NSW Threatened Species Scientific Committee, 2012).

The risk of erosion is increased because lower soil moisture content leads to more rapid oxidation of organic matter and loss of soil cohesion. As the swamps have relatively low clay contents, dry sandy sediments are eroded easily. Peaty sediments crack into blocks that are readily dislodged if an open channel develops. The dry conditions mean that the consequences of major fires for the development of gully erosion can be greater. Once formed, gullies persist because surface water flow is now channelized and sediment cannot accumulate on the bedrock floor.

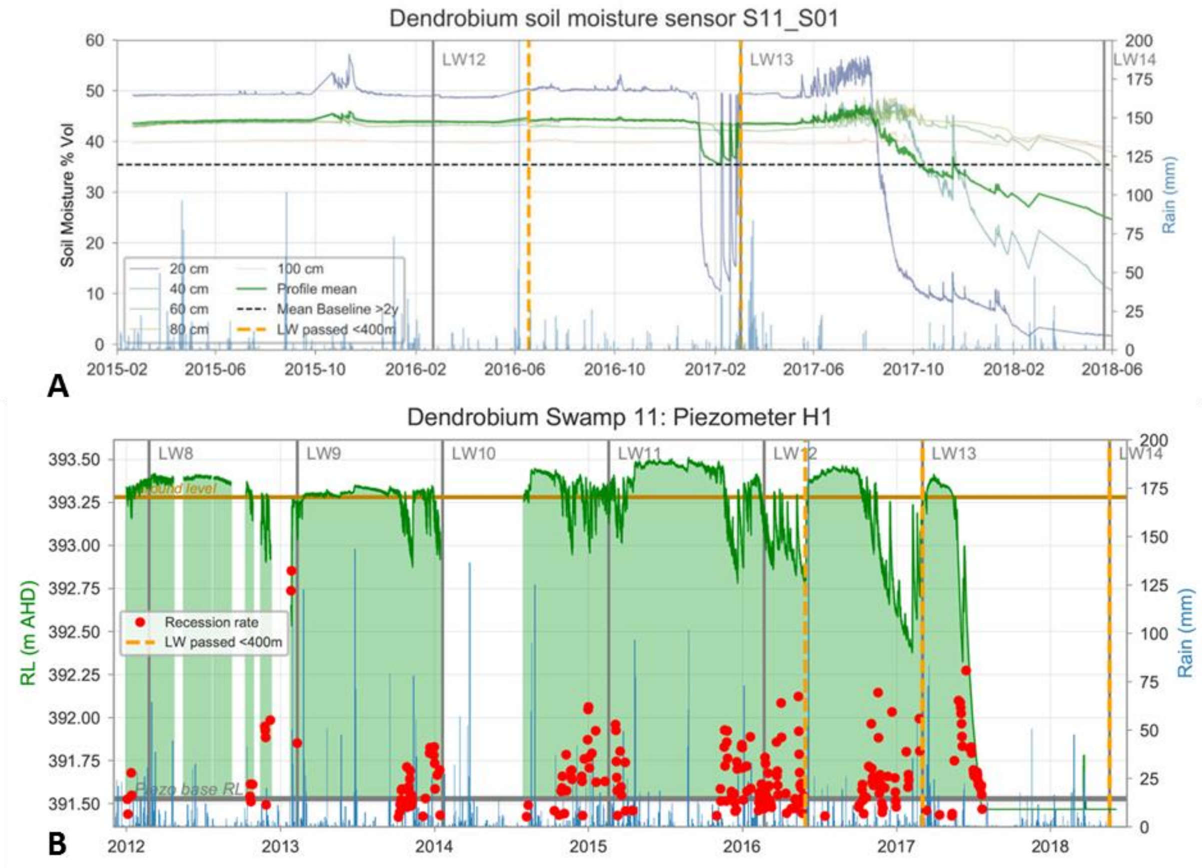

Figure 13: Dendrobium Swamp 11 A) soil moisture profiles and B) associated piezometer hydrograph
Source: HGEO (2017b)

4.3 ECOLOGICAL CONSEQUENCES

The Panel has adopted the generally accepted definition of ecology as *that branch of ecology that deals with the relations between living organisms and their environment.* It considers 'living organism' to comprise flora and fauna.

In its submission to the Panel, OEH described the link between hydrological and ecological consequences as:

> *"Deformation or alteration of the land surface does not in itself have direct impacts to all species and communities occurring above a longwall coal mine. However, water dependent species and communities are highly susceptible to the impacts of subsidence, particularly loss or diversion of surface water. Geological impacts from longwall mining have hydrological impacts, which in turn have ecological impacts on terrestrial and aquatic ecosystems."*[43]

In the case of Metropolitan Mine, the MCP PAC reported that there was no convincing evidence before it that identified any individual swamp or group of swamps in the Project Area as being sufficiently unique or different so as to require identification of 'special significance' and thus requiring special consideration in a risk assessment framework. The PAC therefore considered what were the potential impacts of mining on upland swamps in the Project Area generally and what consequences might follow from such impacts.

The MCP PAC reported that evidence provided to it strongly supported the position that for swamps to experience adverse environmental consequences, changes to swamp hydrology

[43] Submission No.20, Office of Environment and Heritage

would have to occur that were large enough and of sufficient duration to create conditions that were favourable for drying, erosion, fire, or changes in species composition. In the case of species compositional change, it stated that there may be a substantial biological lag (up to decades) before any impact is apparent.

It concluded that the:

> *"consequences of mining impacts on swamps depends upon a wide variety of factors – such as how much water is lost, over what period, whether 'self-healing' occurs, and whether there are severe rainfall events or fire events. Depending on these factors and their interactions a swamp could show no evidence of change, or be severely damaged over a relatively short space of time."*

The MCP PAC noted a range of limitations in the information being relied upon by parties to draw conclusions as to mining impacts on swamps. It recommended that:

> "*future Director-General's requirements for vegetation surveys in relation to upland swamps should specify that the surveys are to be of an adequate standard and intensity to detect the presence of valley infill vegetation associations where these might reasonably be expected to occur."*

It also concluded that:

> *"It is abundantly clear to the Panel (as predicated in the SCI Report) that the knowledge base is extremely limited with respect to the prediction of consequences of undermining individual swamps".*

In its final determination, related to listing of Coastal Upland Swamps as endangered ecological communities, the NSW Scientific Committee (2012) noted that the impacts of longwall mining are "*difficult to predict and detect due to non-linearities and complex dependencies on geological features and mine characteristics, time lags in hydrological and ecological responses and stochastic influences such as rainfall variation during and after subsidence*" and *"changes in species composition resulting from subsidence may not be fully evident until multiple fire cycles after the completion of mining operations"*.

The Panel concludes that the situation largely remains unchanged with respect to the prediction of ecological consequences for swamps and the significance of these consequences. Discussion in relation to mining consequences for flora has centred largely around the rate of any change in species diversity and density, the separation of changes from natural changes due to climatic variation or fire regime, the appropriate monitoring and control systems, the appropriateness of TARPs and vegetation mapping to establish a baseline.

Monitoring over some 10 years has not generally distinguished mining-related changes from natural changes to the upland swamp vegetation communities. The reasons include a lack of adequate baseline data, difficulties in distinguishing mining effects from the effects of natural changes such as fire and climatic variation, the difficulty of identifying appropriate control sites (given differing swamp sizes and distribution of vegetation communities within swamps) and current limitations in defining measures that relate vegetation changes to hydrological changes.

Swamp 28 at Metropolitan Mine provides an example of swamp vegetation being impacted by mining. Changes in water level triggered an assessment against the biodiversity subsidence impact performance measure.[44] The assessment concluded that the performance measure has not been exceeded; however the performance indicator[45] for Swamp 28 has been exceeded. The vegetation monitoring indicated that there is "*a continuing decline in the vegetation condition of Swamp 28, particularly with regards to*

[44] Performance measure: "*Negligible impact on threatened species, populations, or ecological communities"* (Peabody, 2019a)
[45] Performance indicator: "The vegetation in upland swamps is not expected to experience changes significantly different to vegetation in control swamps" (Peabody, 2019a)

condition of understorey species, loss of species richness and mortality of indicator species" (Peabody, 2019a).[46]

A long-term study above Dendrobium Mine illustrates some of these aspects. Although monitoring was undertaken for 11 years in Area 2, 7-13 years in Area 3A and 4 years in Area 3B, no firm conclusions could be drawn about mining impacts on swamps because of caveats about the influence of natural changes and conditions (South32, 2017a). The site where changes were particularly significant was Swamp 1 which, notably, had been undermined for the longest period and is located in Area 2, which is generally acknowledged to have been impacted by connective fracturing from mine workings to the surface. At this swamp, the study recorded *"visible increase in seedling recruitment and persistence of flora species not expected to occur within an upland swamp".* Total species richness at Swamp 1 appeared to be more variable post-mining but species composition changes were driven by '*common upland swamp flora species'*.

Mining history adds another complication (Evans & Peck, 2014). In the Wonga East domain above Russell Vale Mine, it has been suggested that "*existing vegetation has had time to adapt to any change in swamp hydrology due to mining dating back some 50 years*". The moot point is to what extent the present vegetation in Wonga East has adapted to water table changes resulting from mining several decades ago, rather than being determined by the topography, soils and hydrology of the terrain in the area. It is possible that swamps dominated by sedgeland and banksia thicket may persist after some bedrock cracking, but swamps with sub-communities more dependent of sustained high water tables such as tea tree thicket and cyperoid heath may suffer greater consequences.

The Panel concludes that vegetation change assessment to date does not provide a clear and timely measure of possible changes in ecosystem functionality of the upland swamps. This means that it has been of limited value as a performance indicator. This may be resolved in part by changes in methodology. For example, the Independent Monitoring Panel for Springvale mine (Galvin, Timms, & MacTaggart, 2016) recommended that quantitative monitoring data should be supplemented by an overview of the whole swamp and assessment of changes in biomass. Use of targeted obligate swamp-dependent species (either plants or animals) may be a more reliable and timely indicator of ecological consequences than measures such as total species richness of vegetation. However, the decadal nature of many changes still remains a barrier to distinguishing between mining-induced variations and natural variations.

It appears in relation to fauna, there has been little work undertaken in the Special Areas to measure mining impacts on swamp fauna, including obligate swamp species. As far the Panel can determine, the finding that there is no resident population of the eastern ground parrot (*Pezoporus wallicus wallicus*, which is listed as vulnerable in NSW) constitutes the only assessment to date of a swamp-dependent threatened species in the Southern Coalfield. The giant dragonfly has been found on the Woronora Plateau above Russell Vale Mine, but no systematic survey of its distribution has been undertaken. Nor have any studies of stygofauna[47] been undertaken in relation to current mining areas. Studies at swamps further south on the Woronora Plateau found rich stygofaunal assemblages which were greatly influenced by fluctuations in water tables, especially by declining levels (Stumpp & Hose, 2013). However, loss of breeding habitat for some species due to pool level reductions downstream of some swamps has been recognised within the Special Areas, such as Littlejohn's tree frog in the Wongawilli catchment (South32, 2015).

[46] p. 102

[47] Stygofauna or groundwater fauna, are organisms that live underground in water, such as in aquifers.

4.4 MANAGEMENT OPTIONS

4.4.1 Applicability of TARPs to swamps

TARPs are considered by the IESC to be useful in managing impacts on infrastructure and surface features but not "*well suited to managing situations in which:*

- *impacts are small by comparison with impacts that are occurring for a range of other unrelated reasons*
- *impacts may not become apparent for some time*
- *impacts may only become apparent after a tipping point has been reached*
- *the relationships between short-term and long-term impacts are poorly understood."(Commonwealth of Australia, 2014c)*

Swamps constitute one of these situations. In its report on Temperate Highland Peat Swamps on Sandstone (THPSS), the IESC commented that

> *"Industry is increasingly recognising that trigger action response plans (TARPs), a commonly used mitigation measure to predict surface impacts from longwall mining, are an ineffective strategy. This is due to the time lag between onsite mining and the measurement of surface impacts"*; concluding *"Best industry practice would involve development of predictive techniques to recognise risk, and minimising impacts on upland peat swamps before they occur"* (Commonwealth of Australia, 2014b).

This view was reiterated in the IESC Advice on the Springvale Mine Extension project, the IESC noting *"that mitigation or management actions implemented as a component of a TARP, have been unsuccessful in preventing impacts to, or restoring the ecological function of, any THPSS."* (IESC, 2014)

In its 2015 report *Mining Impacts at Dendrobium Coal Mine Area 3B*, the Department stated it did not fully agree with the IESC view regarding the ineffectiveness of TARPs. It considered appropriate TARP triggers, coupled with monitoring procedures such as the measurement of soil moisture, identifying changes in water table and increased rates of groundwater level recession through shallow piezometers and hydrographs, can be effective as early indicators of impacts on upland swamps; noting OEH advice that TARPs can provide an effective framework "*but must have performance triggers that are effective within a timeframe meaningful to a regulatory response*". The Department concluded that until a better alternative was identified, it would continue to consider TARPs as a useful monitoring and management tool (DPE, 2015).

The Panel's conclusion in the Initial Report that TARPs *"do not reflect the groundwater dependence of the upland swamp ecosystems"* was challenged in Peabody's response that *"swamp impact TARPs do include triggers associated with piezometer monitoring"* (Peabody, 2019b).[48] The Panel recognises that TARPs for changes to piezometric levels in shallow groundwater are defined for both Dendrobium and Metropolitan mines.

The Panel's conclusion about the groundwater dependence of swamps goes to the issue of existing TARPs defining ecosystem functionality predominantly by consequences (vegetation change and erosion) that may take years or decades to be measurable and clearly separable from natural variation. Furthermore, there are no TARPs specified for the few piezometers in bedrock adjacent to upland swamps, yet data from these are essential to understand to what degree groundwater in swamp sediments is supported by shallow groundwater in the bedrock both pre-mining and post-mining.

By definition, swamps are groundwater-dependent ecosystems. Therefore, a change in piezometric levels should be the primary gauge of impacts on the ecosystem. If maintenance

[48] Note: The Panel has accepted this submission and the conclusion has been updated in the Part 1 Report.

of ecosystem functionality is to be mandated for any swamp, then piezometric variation must be used not only in TARPs but also in performance measures.

4.4.2 Swamp Offsets

The SCI reported that it was not aware of any attempts to remediate fracture networks beneath swamps. However, current grouting techniques did not appear suitable for this purpose. It recommended consideration be given to the increased use of environmental offsets to compensate for impacts on natural features.

The MCP PAC recommended an approach for considering the acceptability or otherwise of negative environmental consequences for swamps. This was also adopted by the BSO PAC and based on the premises that:

> *"….negative environmental consequences are considered undesirable for all swamps and:*
>
> *a) swamps of special significance will be protected from negative environmental consequences; and*
>
> *b) a presumption of protection from significant negative environmental consequences will exist for all other swamps unless the Proponent can demonstrate for an individual swamp that costs of avoidance would be prohibitive, and mitigation or remediation options are not reasonable or feasible. Under circumstances where the decision is to allow significant negative consequences to occur and remediation is not feasible offsets and other forms of compensation may be considered appropriate."*

Subsequently, the BSO PAC concluded that "*the bottom line appears to be if mine subsidence has the potential to impact on near surface formations to an extent that could cause changes in the hydrology of a swamp, then the swamp is at risk of serious negative environmental consequences in whole or in part".*

Fracture networks beneath swamps fall into one of three basic categories, being:

- Shallow near surface networks associated with conventional subsidence effects and concentrated at reasonably predictable locations over and around the mining footprint
- Shallow near surface networks associated with non-conventional subsidence effects and concentrated in and around valley floors within and up to several hundred meters outside of the mining footprint
- Surface to seam fracture networks which daylight within the mining footprint.

The Panel does not believe it is practical to reverse the impacts of depressurisation by remediating the third category of fractures (surface to seam fracture networks). Further, along with many stakeholders, it is highly sceptical if it is feasible to remediate fracture networks falling into the first two categories when they exist beneath swamps. It is aware that a trial is planned at Dendrobium Mine to test the potential for the remediating the second category of fracture networks beneath a swamp.

This means that in circumstances where it is difficult, if not impossible, to design a viable mining layout that avoids impacting swamps and mining is to proceed, there is little option than to consider offsets as compensation for the consequences of negative environmental impacts on swamps. This is the situation that now exists at Dendrobium Mine following the approval of a Strategic Biodiversity Offset in 2016. Remediation and offsetting of swamps is discussed further in §5.6 and §5.7.

4.5 CONCLUSIONS

a. Since 2008 the collection of monitoring data supported by a substantial body of research has improved understanding of the impacts and consequences of longwall mining for swamps.

b. Nevertheless, the integrated monitoring and modelling needed to understand the contribution of swamps to baseflows continues to be extremely limited and no accurate water balance is available for any swamp in the Southern Coalfield.

c. It is now established that longwall mining directly under swamps in the Southern Coalfield can result in significant changes to swamp hydrology and redirection of surface runoff, which the Panel considers are very likely irreversible.

d. At Metropolitan Mine all swamps undermined to date are small in area and length and any mining-induced fractures are very likely to be confined to the near surface with most, if not all, redirected flow returning to the surface and flowing into Woronora Reservoir. On the other hand, at Dendrobium Mine many of the swamps undermined to date are moderate to large in area, some extend for more than 600 m along watercourses and it is possible that a substantial amount of the water that would normally flow through some impacted swamps is being redirected into the mine workings or other catchments through deep subsurface fracture networks.

e. While impacts on the swamps themselves and on the streams exiting from them are evident, it remains the case that there is no strong evidence to date of consequences of swamp impacts on catchment-scale water supplies.

f. This could change in the future with the benefit of more monitoring information and/or if more mining panels are fractured through to the surface.

g. When shallow groundwater levels in a swamp decline, soil moisture levels also decline, with a lag time of weeks or months.

h. Quantifying the consequences of these changes for flows in exit streams requires the development of water balance models of the swamps.

i. Despite decades of monitoring, mining-induced changes to upland swamp vegetation communities are still not able to be differentiated from natural changes.

j. Vegetation change assessment does not provide a clear and timely measure of possible changes in ecosystem functionality of the upland swamps. While changes in methodology, such as using targeted obligate swamp-dependent species (either plants or animals) may improve assessment, the decadal nature of many changes remains a barrier to distinguishing between mining-induced variations and natural variations.

k. Dehydration of the swamps increases their susceptibility to erosion, especially after severe bushfires.

l. It appears that there has been little work undertaken in the Special Areas to measure mining impacts on swamp fauna, including obligate swamp species.

m. There is very limited, if any, scope for remediating fracture networks beneath swamps. Therefore, in circumstances where it is difficult, if not impossible, to design a viable mining layout that avoids impacting swamps and mining is to proceed, there is little option than to consider offsets as compensation for the consequences of negative environmental impacts on swamps.

4.6 RECOMMENDATIONS

18. Future swamp monitoring and modelling programs should be designed to:
    a. Provide a hydrological balance for representative swamps, sufficient to identify any mining-induced changes in soil moisture and in baseflow down the exit stream; and to provide vertical leakage rates as inputs to groundwater models, in order to quantify how much of the leakage is diverted back into the catchment or elsewhere.
    b. Link any changes in swamp vegetation to changes in water table position, soil moisture content and soil organic carbon content.
    c. Identify the presence of and any changes in obligate swamp fauna such as the giant dragonfly (*Petalura gigantea).*
19. Government should continue to support and/or carry out independent research (possibly on a cost recovery basis from the mining sector) to provide regional information on swamp hydrology and ecology. In particular, continuation of monitoring at sites where there is a substantial basis of data should be a priority.
20. Annual performance reports, end-of-panel reports and reports on studies required by development consent conditions, should:
    a. integrate hydrological and ecological impact and consequence assessments
    b. include discussion of the inter-related changes in hydrological and ecological consequences for swamps, rather than having only discrete chapters on each
    c. include results for the entire period of monitoring, rather than just the previous year, that should be assessed, not only for the current mining area but for previous mining domains.

5 ADDITIONAL MATTERS

This chapter discusses a number of additional matters arising out of submissions, the Panel's Term of Reference 2 to review and update relevant findings of the SCI, and the experiences of the PAC in applying the findings of the SCI. Given the breadth and unrelated nature of many these matters, conclusions and recommendations (where drawn) are incorporated in each section of this chapter rather than, as in other topic specific chapters, consolidated at the end of the chapter.

5.1 REGULATORY DEVELOPMENTS SINCE SCI

International trends in regulation have evolved from *prescriptive* approaches focused on inputs and defining how activities should be undertaken, to *outcomes-based* approaches centred on ends to be achieved. Common principles include evidence-based decision making supported by risk assessments, and a cascade of compliance and enforcement options available to regulatory authorities to ensure interventions are proportionate and effective, with net benefits outweighing costs.

Consistent with these trends and NSW planning reforms, mining applications in NSW are now subject to an outcomes-based and iterative development approval process to manage subsidence risk. This has resulted in some complexity as approvals have been granted at different points in time under different regulatory regimes.

Mining in the catchment predated the declaration of Special Areas and mining approvals were historically managed under mining and not environmental or planning legislation. Reforms from the early 2000s include changes to the way major projects are assessed and gradual integration of approval requirements under multiple legislative instruments. A detailed account of the current framework is provided in Appendix 2 of the Part 1 Report.

Amendments to the EP&A Act in 2005 removed previous exemptions for coal mines from the requirement to obtain development consent under that Act; transitional provisions giving mines until 2010 to obtain approval[49]

Further reforms integrated the responsibilities of other agencies into the planning process, including those under *the Mining Act 1992*. Consistent with this, a consolidated EP (including subsidence management) has been required as a condition of Consent (under the EP&A Act) since 2014, replacing SMPs previously required since 2004 as part of mining leases (under the Mining Act).

Although specific approvals are not required under the Aquifer Interference Policy (2012), its provisions inform the assessment of proposals. The Metropolitan Water Plan was updated in 2017 and water sharing plans (which include environmental flow rules) have been developed to provide for sustainable and integrated management of water resources in accordance with the *Water Management Act 2000*. In 2012, the Coastal Upland Swamps were listed under NSW law as an Endangered Ecological Community and in 2014 as Threatened Ecological Communities under Commonwealth law.

The *Biodiversity Conservation Act 2016* includes a statutory-based method to offset adverse environmental impacts; the addendum providing a framework to measure and address the

[49] The *Environmental Planning &Assessment (Infrastructure and Other Planning Reform) Act* 2005 commenced a program of major reforms to the planning process (NSW Parliamentary Library Research Service, 2010). Subsequent reforms including the *EP&A Amendment (Part 3A Repeal) Act 2011* refined the assessment pathway for State Significant Developments (SSDs), which includes development for the purposes of coal mining. Environmental assessment requirements for major projects were then referred to as Director-General's Requirements or DGRs, now known as Secretary's Environmental Assessment Requirements or SEARs.

impact of subsidence from longwall mining on upland swamps.[50] Other reforms since the SCI Report include the establishment of WaterNSW through the *Water NSW Act 2014* (a merger of the Sydney Catchment Authority and State Water Corporation) and establishment of the Natural Resource Access Regulator under the *Natural Resource Access Regulator Act 2017*. In 2017, the Rehabilitation Cost Estimation Tool and Guidelines were updated, including to the rehabilitation activities cost schedule and the requirement that rehabilitation meet an agreed land use.[51] At the Commonwealth level, the IESC was established in 2012 to provide expert advice on water-related impacts of coal seam gas and large coal mining developments. In 2013, the *Environment Protection and Biodiversity Conservation Act 1999* was amended, establishing water resources as a matter of national environmental significance in relation to coal seam gas and coal mining developments (referred to as the 'water trigger').

5.2 PRECAUTIONARY PRINCIPLE AND ADAPTIVE MANAGEMENT

Recommendation 15 of the SCI was that:

> *Coal mining companies should develop and implement:*
>
> - *approved contingency plans to manage unpredicted impacts on significant natural features; and*
> - *approved adaptive management strategies where geological disturbances or dissimilarities are recognised after approval but prior to extraction.*

A number of submissions to the MCP PAC and the BSO PAC raised the application of the Precautionary Principle in relation to the potential for serious environmental consequences, especially for upland swamps.[52] The BSO PAC noted that there are several definitions of the Precautionary Principle including the one in s.6(2) of the *Protection of the Environment Administration Act (1991) NSW* which states that:

> *"…if there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation.*
>
> *In the application of the precautionary principle, public and private decisions should be guided by:*
>
> *(i) careful evaluation to avoid, wherever practicable, serious or irreversible damage to the environment, and*
>
> *(ii) an assessment of the risk-weighted consequences of various options"*

The BSO PAC approached the matter by examining some of the various definitions used for describing the principle, examining the relevant case law and then applying the principles from the cases to the facts of the BSO Project as it related to upland swamps. It reported that the two cases of most relevance are *Telstra Corporation Limited v Hornsby Shire Council [2006] NSW LEC 133 (Telstra)* and *Newcastle and Hunter Valley Speleological Society Inc v Upper Hunter Shire Council and Stoneco Pty Limited [2010]* NSW LEC 48 (Stoneco), with the first case (Telstra) setting out in clear detail the factors to be considered in applying the Precautionary Principle.

Both *Telstra* and *Stoneco* discussed adaptive management as a possible way to proceed with a development by limiting the opportunity for impacts, monitoring the results of early

[50] Addendum to NSW Biodiversity Offsets Policy for Major Projects - Upland swamps impacted by longwall mining subsidence (2016)
[51] The Tool and Guidelines are used to estimate rehabilitation liabilities. Land disturbed by exploration, mining and petroleum production activities is required to be rehabilitated and returned to a sustainable land use.
[52] e.g. Total Environment Centre, Colong Foundation for Wilderness, National Parks Association in the case of the BSO Project.

work, and then adjusting the project to maintain the required outcomes. The following extracts are particularly relevant to the Panel's Terms of Reference.

In the Telstra matter, the Court noted that:

> *"One method discussed for achieving an appropriate level of precaution was adaptive management – based on the project being constrained in the area of uncertainty and only allowed to expand as the uncertainty reduced. The key elements include: monitoring of impacts based on agreed indicators; promoting research to reduce key uncertainties; adjustment of the activity based on the results and an efficient and effective compliance system" (PAC, 2010).*[53]

In the Stoneco matter, the Court applied a step-wise adaptive management approach to risk management, stating that:

> *"Adaptive management is a concept which is frequently invoked but less often implemented in practice. Adaptive management is not a "suck it and see" trial and error approach to management, but it is an iterative approach involving explicit testing of the achievement of defined goals. Through feedback to the management process, the management procedures are changed in steps until monitoring shows that the desired outcome is obtained. The monitoring program has to be designed so that there is statistical confidence in the outcome. In adaptive management the goal to be achieved is set, so there is no uncertainty as to the outcome and conditions requiring adaptive management do not lack certainty, but rather they establish a regime which would permit changes, within defined parameters, to the way the outcome is achieved"* (PAC, 2010).[54]

Submissions indicate differing understandings of how the concept of adaptive management should be interpreted, as well as continuing concerns about the application of the principle in practice. This appears to the Panel to be exacerbated by legacy approvals which enable certain mining activities to proceed that might be approached differently under current knowledge and approvals processes.

Nevertheless, adaptive management has been applied successfully, both at mines operating under contemporary approvals and at mines operating under older approvals. Two examples in the Special Areas relate to protection of Sandy Creek Waterfall at Dendrobium Mine (Walsh et al. (2014a, 2014b); Walsh et al. (2014c)) and to the protection of the lower end of the Eastern Tributary at Metropolitan Mine (see §5.10). In both cases, adaptive management informed the termination point of longwall panels to avoid impacts on natural features.

5.3 REVERSE ONUS OF PROOF

Recommendation 5 of the SCI stated that:

> *"due to the extent of current knowledge gaps, a precautionary approach should be applied to the approval of mining which might unacceptably impact highly-significant natural features. The approvals process should require a 'reverse onus of proof' from the mining company before any mining is permitted which might unacceptably impact highly-significant natural features. Appropriate evidence should include a sensitivity analysis based on mining additional increments of 50 m towards the feature. If such mining is permitted because the risks are deemed acceptable, it should be subject to preparation and approval of a contingency plan to deal with the chance that predicted impacts are exceeded".*

The MCP PAC did not support this concept. It pointed out[55] that it contains two major qualifying expressions, namely *'unacceptably impact'* and *'highly-significant'* and that both of

[53] p.125
[54] p.126
[55] p. 43

these require subjective judgements given the current state of knowledge about the relationship between predicted subsidence impacts and observed consequences for natural features and the lack of capacity to quantify significance. The PAC went on to note that the concept also used the legal standard of 'balance of probabilities' as the single standard to which the Proponent must prove its case. This was considered to be simply the legal expression of 'more likely than not' or '51%:49%' and, as such, may be suited to some kinds of risks and not others. For example, if the risk is decreased yield to the Woronora Reservoir then a higher level of assurance might be required from the Proponent than, say, a possibility that the hydrology might be altered in part of a single swamp.

The MCP PAC also concluded that the single standard may also not be suited to some 'highly-significant' natural features where there needs to be much greater assurance of no negative consequences, particularly where the response of the feature to increasing subsidence impacts is stepped rather than linear. It noted that a number of submitters, including two government agencies, attempted to turn the concept into a requirement for a Proponent to prove beyond reasonable doubt that no consequences would occur if undermining of the feature was approved. Given the knowledge gaps in the relationships between subsidence impacts and consequences for natural features, and the poor databases for many key features in the region, the PAC considered that this would effectively put the Proponent in the position of trying to prove the unprovable. It concluded that the concept was not useful in its current form and should be replaced.

The Panel has reviewed the concept and tested its application to some of the matters it has considered.

5.3.1 Conclusions

The Panel concludes that:

a. The concept of Reverse Onus of Proof as espoused in the SCI Report is unworkable.

b. The concept of Reverse Onus of Proof has been superseded in practice by the requirement for a Proponent to demonstrate the reasonableness (or overall merit) of its proposals in relation to the significant natural features that may be exposed to subsidence impacts, thereby enabling the decision-maker to assess reasonableness (or merit) in the context of the importance of the features, the predicted risks and any management options for those risks.

5.3.2 Recommendation

21. The concept of Reverse Onus of Proof should be discarded.

5.4 RISK MANAGEMENT ZONES

5.4.1 Southern Coalfield Inquiry

The SCI recommended a range of improvements in the way that EAs for project applications lodged under Part 3A (now Part 4) address subsidence effects, impacts and consequences. These included:

1. Identification and assessment of significance for all natural features located within 600 m of the edge of a secondary extraction panel;
2. The establishment of Risk Management Zones (RMZs) for all significant natural features in order to focus assessment and management of potential impacts, with a RMZ being defined from the outside extremity of a surface feature, either by a 40° angle from the vertical down to the coal seam which is proposed to be extracted, or by a surface lateral distance of 400 m, whichever is the greater (and including the footprint of the feature itself).

3. The establishment of RMZs for all streams of 3rd order or above, in the Strahler stream classification, for valley infill swamps not on a 3rd or higher order stream and for other areas of irregular or severe topography, such as major cliff lines and overhangs not directly associated with watercourses.

The SCI stated that the identification of RMZs was not intended to represent either a determination of 'significance' or to suggest or require the exclusion of mining. Rather, the purpose was to flag that proposed mining within the zone requires careful assessment, and potentially careful management. Management outcomes may potentially be threefold. If the feature within the RMZ is not highly significant and/or not highly sensitive, then a standard subsidence management regime may apply. If it is highly significant or sensitive, then strict management and performance standards should be applied. If the feature is both highly significant and highly sensitive, then predicted impacts and consequences may be deemed unacceptable by Government and longwall mining may not be permitted to proceed close to the feature. The SCI considered that this approach would provide greater focus and emphasis on specific natural features, provide specific parameters where such increased focus is to be applied, and promote more rigorous risk assessment taking account of all stakeholder input.[56]

The SCI also considered that the RMZ concept could be readily incorporated into the mining development consent process. It was of the view that RMZs should initially be identified by mining proponents, subject to additional input from key agencies and other stakeholders via early engagement and the planning focus process, with the Department having the final responsibility for identifying the location and lateral extent of RMZs. This identification should be in the DGRs (now SEARs)[57] issued for preparation of an EIS. Further, the Department's final assessment report, which is provided to the consent authority in considering whether to grant consent, should be structured in such a way as to give clear consideration to the various RMZs associated with the application. Development consent should then provide clear conditions and performance standards for mining or subsidence within RMZs which should be addressed within the SMP (or EP).

5.4.2 Planning Assessment Commission Reviews

The concept of RMZs post-dated the DGRs for both the MCP and the BSO development applications. However, the MCP PAC gave careful consideration to the possible use of the RMZ concept in its review and recommended an expanded risk framework for natural features. This set out suggested approaches for assessing relative significance of natural features and the acceptability or otherwise of subsidence-induced impacts and consequences for those features. It recommended that the expanded process be considered for inclusion in future requirements for the assessment of proposals for mining in the Southern Coalfield to ensure that appropriate information on risks to significant natural features is available in an EA.

The BSO PAC concluded that

> "*there is a problem with allowing the Proponent to assess what is of 'special significance' and what is not. Attribution of special significance to an item or feature carries with it a requirement for a much higher level of scrutiny and consideration of protection and may therefore require changes to the mining proposal. The Panel in the Metropolitan PAC Report noted that there was an element of subjectivity in the allocation of special significance status. The Proponent's subjective view yielded one (possible) item of special significance in the whole 220 km^2 of the Study Area – the Nepean River. None of the other 46 streams classed as 3rd order and above, none of the 226 upland swamps, none of the 634 cliffs (including Appin Falls) and none of the 632 Aboriginal Heritage Sites in the Study Area succeeded in crossing the*

[56] SCI Report, p. 111

[57] Previously Director-General's Requirements or DGRs. These are now known as Secretary's Environmental Assessment Requirements or SEARs.

Proponent's threshold for special significance. This was in stark contrast to the submissions by government agencies, special interest groups and the public, which identified many such items, usually supported by credible evidence."

The BSO PAC addressed this situation by applying the expanded RMZ concept adopted in its assessment of the MCP.

5.4.3 Current Situation

Depressurisation of the overburden and the potential consequences this could have for both natural and built features have assumed greater importance since the SCI and the MCP PAC and BSO PAC. Neither the lateral extent of impacts due to depressurisation nor the consequences for subsurface features and built surface features appear to have been considered at the time that the SCI defined the boundary limits for RMZs. It needs to be established in the light of more recent field monitoring if there are circumstances where the size of RMZs as originally proposed needs to be increased for risk assessment purposes.

SEARs were issued for the Tahmoor South Coal Project on 20 June 2018 and for the Dendrobium Mine Extension Project on 18 September 2018. Neither made provision for the establishment of RMZs or for stakeholder engagement in identifying natural (and built) features of special significance. However, both list general requirements that incorporate many elements of the RMZ concept as expounded by the SCI and the PAC.

The EIS for the Tahmoor South Coal Project that was recently submitted to support the development application is based on identifying all natural features within the 20 mm vertical surface displacement contour or within 600 m of the extremity of longwall extraction, whichever is greater, and has specific regard to the establishment of RMZs for surface features, noting that:

"The principles of mine design for the proposed development involved a risk management approach in the context of recent publications regarding impacts of longwall mining in the Southern Coalfields.

These include:

- *the 2008 Southern Coalfield Inquiry (Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield – Strategic Review);*
- *the Thirlmere Lakes Inquiry Chief Scientist and Engineer reports; and*
- *the NSW Planning and Assessment Commission (PAC) reports for Metropolitan Coal Project and*
- *the Bulli Seam Operations Project."*

The EIS for the Dendrobium Mine Extension Project is also based on identifying all natural features within the 20 mm vertical surface displacement contour or 600 m of the extremity of longwall extractions, whichever is greater, but is silent on RMZs.

The Panel has not assessed the two different approaches. However, it notes that the SEARs for both projects require a number of specific issues to be addressed that are key elements of the concept of RMZs. Some also relate directly to assessing the impacts and consequences of depressurisation for natural and built features and includes water quantity and quality in the Special Areas.

5.4.4 Conclusions

The Panel concludes that:

a. the concept and intent of RMZs is reflected in current SEARs, albeit that the mechanism which gives effect to the concept is not prescribed to the extent proposed by the SCI and PAC assessment panels a decade ago.

b. It should be established if there are circumstances where the size of RMZs, or their conceptual equivalent, need to be increased for risk assessment purposes to properly account for the consequences of groundwater depressurisation.

5.5 CUMULATIVE IMPACTS

Based on the definitions of the SCI, the term *cumulative impacts* may be separated into:

- cumulative effects (accumulation of subsidence due to mining)
- cumulative impacts (accumulation of cracking and other subsurface and surface deformation due to cumulative effects)
- cumulative consequences (water losses, and associated environmental, social and economic consequences, resulting from cumulative impacts of mining and/or from the impacts arising from other activities and influences in the catchments).

Cumulative consequences may arise from the effects and impacts of mining, but also from a range of effects and impacts of agricultural activities, urban development, reservoir construction, climate variability and change, bushfires, and other human activities and natural influences in the Special Area catchments. These may act independently or in combination.

Cumulative effects, impacts and consequences are required to be considered in the planning and assessment process under the *Environmental Planning and Assessment Regulation 2000*, which requires that *"any cumulative environmental effect [of a proposed development] with other existing or likely future activities"* must be taken into consideration when assessing the environmental impact of that development.

The broad general definition of cumulative effects, impacts and consequences requires that the scope of any assessment should be clearly defined in terms of spatial scale, temporal scale, and types of impacts being considered. While there may be a range of (positive and negative) environmental, social and economic-related consequences associated with mining in and around the Special Areas, the discussion here is limited to water quantity losses in the Special Areas and consequences on water supplies for Greater Sydney. In this context, cumulative consequences may refer to:

1. The accumulation of water supply losses over time, including losses due to the progression of mining, increased subsidence in some multi-seam situations, and other interactions between current and historical mines, or the progression of drought conditions over time
2. The accumulation of water supply losses over multiple catchments and reservoirs in the Special Areas
3. The accumulation of water supply losses due to a combination of factors, for example mining and climate change[58]
4. The accumulation of reductions in quality of water

Other influences on the Greater Sydney's water supply and demand, including desalination plants[59], borefields, housing development, population growth[60], and water restriction rules

[58] The NSW and ACT Regional Climate Modelling (NARCliM) Project has developed local scale climate projections for NSW for the near (2020-2039) and far (2060-2079) future. Climate projections for the Illawarra region indicate temperature increases, changes in rainfall patterns (increases in autumn and decreases in spring and winter), increase in hot days and a decrease in cold nights. Projected temperature increases and changes in rainfall patterns are likely to lead to additional pressure on water resources in the catchments which need to be considered as part of cumulative impact assessments.

[59] The Sydney Desalination Plant was restarted in January 2019 when total dam storages across Sydney fell below 60 percent. Desalinated water was supplied to Sydney Water in March 2019. Potential impacts from the Desalination Plant include energy usage (~38 Megawatts, this is offset by the Capital Hill Wind Farm at Bungendore), land, and water impacts (Sydney Desalination Plant, 2019).

are also important if considering how these water quantity losses impact planning of the water supply system.

Challenges of quantifying cumulative consequences of mining on surface water losses are covered in Chapter 3 of this report.

5.5.1 Knowledge of cumulative impacts on water losses in the Special Areas and previous recommendations

The general lack of data and knowledge pertaining to cumulative consequences of historic, current and future mining activity in the Special Areas is a primary concern raised in consultations.

The lack of knowledge was recognised in the SCI Report, which concluded: *"In all fields, there is a lack of regional and cumulative data records, over time, and subsequent review and assessment of cumulative and regional impacts".* More recently, the 2016 Catchment Audit, while not finding quantitative evidence of cumulative impacts of mining on water losses, confirmed the gap in knowledge: *"The Audit found an emerging issue of unquantified loss of surface flows associated with the cumulative impacts of underground coal mining activities …. Greater understanding of the effect of multiple mine workings on Catchment water yield is required"* (Alluvium, 2017).

The SCI Report recognised the importance of cumulative impacts assessment and recommended that "*Regulatory agencies should consider, together with the mining industry and other knowledge holders, opportunities to develop improved regional and cumulative data sets for the natural features of the Southern Coalfield, in particular, for aquatic communities, aquifers and groundwater resources".* The 2016 Catchment Audit recommended these steps*: "Compile all empirical evidence of mining impacts in the Sydney Drinking Catchment in a regional cumulative impact assessment"* and *"Establish the scope and commence a state-owned regional surface water and groundwater geotechnical model"* (Alluvium, 2017).

WaterNSW, in their submission to the Panel, support the vision of a government owned regional model; however, the submission also states that a pre-requisite for a regional model is the development of better understanding of the impacts of longwall mining on water volumes, water quality and ecological health (WaterNSW, 2019b). Based on the NSW Chief Scientist & Engineer's (CSE) Cumulative Impacts report (NSW Chief Scientist & Engineer, 2014), WaterNSW conclude, *"that the current state of understanding of these issues is insufficient to enable an integrated numerical model to be developed"* (WaterNSW, 2019b).

DoI Water also noted reservations about the objective of developing a regional water balance model for the following reasons:

- It would require the "*standardisation of monitoring data collection, reporting and distribution*".
- issues around scaling
- limited baseline data

Four of the five recommendations of the CSE's Cumulative Impacts report (NSW Chief Scientist & Engineer, 2014) relevant to understanding cumulative impacts of mining in the Special Areas are:

1. *"That Government create a whole-of-Catchment data repository.*
2. *That Government develop a whole-of-Catchment environmental monitoring system.*

[60] Population and housing projections for 2036 anticipate that Greater Sydney will have an additional 1.74 million people and require a minimum of 725,000 additional dwellings (Greater Sydney Commission, 2017)

3. *That Government commission computational models which can be used to assess the impacts on quantity and quality of surface water and groundwater.*
4. *That Government establish an expert group to provide ongoing advice on cumulative impacts in the Catchment."* (NSW Chief Scientist & Engineer, 2014)

5.5.2 Databases and assessing cumulative impacts

Previous reviews on the Southern Coalfield and the Greater Sydney water catchment have indicated the need for and/or recommended the development of open databases prior to attempting regional cumulative impacts assessment (Hebblewhite et al., 2008; NSW Chief Scientist & Engineer, 2014; Alluvium, 2017).

While consultations have indicated that the data sets collected by operating mines may be available on request, the absence of a single data base and data management protocol continues to restrict accessibility and ease of use of these data by all stakeholders for developing understanding of cumulative water losses.

The Sharing and Enabling Environmental Data portal (SEED) was developed in 2016 by the NSW Government to address the lack of access to raw data, particularly baseline data, including data collected by industry.

The coordination and centralisation of data collected by government and industry has a number of advantages. These include increasing the efficiency of assessments, improving regulatory and compliance activities, expanding the knowledge base (groundwater, surface water, geology, flora and fauna), reducing costs and delays associated with poor data availability, increasing transparency and enabling better decision making in relation to multiple activities and cumulative impacts.

The Panel's recommendation in the Part 1 Report for the development of standards for data collection and to facilitate more effective sharing (such as on SEED) and use of data received particular support from government agencies during consultations and in submissions.

The Queensland Office of Groundwater Impacts Assessment has been responsible for assessing the cumulative impacts of resource development on groundwater resources in the Surat Cumulative Management Area since 2011. This includes maintaining a database of government and coal seam gas (CSG) company data, and developing a 3D regional groundwater model. The model is updated as new information is obtained and an updated impact report is published following consultation approximately every three years. In this case, surface water resources are not the focus because they are of lower significance than groundwater in the Surat region. The primary focus has been on CSG but coal mining is also included.

This serves as an example of how state government office, financed by the extractors, can take responsibility for a cumulative impacts assessment that incorporates multiple extractive projects, with the office's role including management of the supporting database, groundwater models, and engagement with key stakeholders.

The Panel is of the view that a centralised data base may have long term value in informing mine closure and lease relinquishment in years/decades to come and in maintaining closed mines in perpetuity.

5.5.3 Conclusions

The Panel concludes:

a. that the development of open databases could substantially benefit:
   i. quantifying regional cumulative impacts assessment, both in the short term and the long term
   ii. transparent and objective assessment of mining proposals

iii. mine closure planning and post-closure management

5.5.4 Recommendation

22. Environmental data from mine companies should be housed in a centralised data portal, such as the SEED portal, prioritised according to its value in assessing cumulative impacts of concern.

As stated in §3.3.5, the Panel does not recommend development of a new regional scale model covering the Special Areas at least until the knowledge base is substantially developed, having regard to the challenges identified in this Report.

5.6 REMEDIATION

There has been limited remediation of environmental impacts in the Special Areas to date, however a number are planned. In most cases, because subsidence develops incrementally over a number of longwall panels, remediation has to be delayed several years until subsidence effects have plateaued.

The SCI Report discussed available techniques for the remediation of significant natural features impacted by mining subsidence such as backfilling and/or grouting of cracks and fracture networks, stabilisation of slopes and draining and erosion control measures. Since fracture networks can extend for hundreds of metres, remediation efforts had focused on sealing near-surface fracture networks in watercourses at strategic locations such as rockbars.

The SCI Report concluded that remediation efforts had experienced mixed success in watercourses in the Southern Coalfield, including the Georges River (Marnhyes Hole and Jutts Crossing), the lower Cataract River and initial work to use polyurethane resin or PUR at Waratah Rivulet.[61] Importantly, the SCI found that "*While increasing success has been demonstrated in re-establishing pool water holding capacity and stream flow at a number of locations, little effort has been directed towards re-establishing aquatic ecosystems or measuring their return.*"

The SCI Report concluded that *"remediation should currently not be relied upon as a forward management strategy for highly-significant features. However, remediation may be a valuable option as a contingency measure, if actual subsidence impacts exceed predictions*." Both the MCP PAC and the BSO PAC made similar findings. The SCI also identified the need for companies to provide more detailed information about remediation efforts and evidence of their likely effectiveness.

The MCP PAC inspected the site of the PUR grouting on Waratah Rivulet (WRS4) and concluded "*that this technology has a high potential for effectively sealing a fracture network but still requires further development*". They further noted that:

- the "*polyurethane injection also penetrates natural sub-surface flow networks and so may not fully restore the natural environment."*
- *"The durability of the product is not proven. It had the appearance of having undergone shrinkage at some injected cracks observed during the inspections."*
- *"The technique is yet to be evaluated for restoring surface flows to unfractured rockbars that lose surface flow due to diversion of water into upsidence network upstream and offset to the bar."*

The BSO PAC, while acknowledging that there is *"some success at sealing subsurface fractures at specific rockbars, the universal applicability of this technique to restore flow throughout entire lengths of streams is speculative at best*." It also noted that remediation proposals had focussed on the restoration of pools behind rockbars, but for some important

[61] The use of PUR had been used extensively in civil and mining environments but had not been permitted in the Special Areas due to concerns about pollution of water supplies by the (then) Sydney Catchment Authority.

streams, more pools form behind boulder fields and the feasibility of restoring those pools is unproven.

The Panel inspected Waratah Rivulet (WRS3 and WRS4) on 26 March 2018 and commented in the Part 1 Report that grouting has been used to restore rockbars and pools in streambeds.

The Peabody (Metropolitan Mine) submission states that the PUR injection into the rockbars WRS3 and WRS4 on Waratah Rivulet has restored pool levels to pre-impact levels over time.[62] WaterNSW agreed that the remedial grouting has been successful in restoring a substantial proportion of natural flows, but commented that the actual proportion of natural flow cannot be quantified due to inadequate baseline monitoring and a lack of any agreed remedial success methodology.[63] In its submission, the Illawarra Residents for Responsible Mining did not believe the remediation efforts at Waratah Rivulet to be successful and raised concerns about the longevity of the grouting materials and potential need for and commitment to long-term maintenance of the site.[64,65]

Panel members who had walked Waratah Rivulet before remediation were impressed with the visual improvement in ecological values and water quality on the day of the field visit but, like WaterNSW, recognised that the extent of restoration of natural flow and ecological values could not be quantified due to a lack of baseline data. The Panel considers that the concerns of the Illawarra Residents for Responsible Mining regarding the longevity of the grouting materials and potential need for and commitment to long-term maintenance of the site have considerable merit. The SCI recommended that the coal mining industry undertake research into procedures for ensuring the maintenance and security of grout seals in the long term. The Panel was not presented with evidence of that research, which it considers important for informing mine closure planning.

Undermining of WC21 at Dendrobium Mine, which has no performance measures attached to it, has led to changes in the hydrology of the watercourse. This has included fracturing of the bedrock of the stream, draining of surface flow and pool water and surface water diversions leading to increased levels of iron and other minerals. WaterNSW are facilitating access for South32 to undertake a remediation trial of WC21, but note that "*the almost total drying of this stream and supporting aquifer makes the likelihood of recovering natural flows very low"* and that South32 acknowledge that the trial *"is limited to targeted pools draining more slowly following rainfall, which may allow these pools to provide some refuge for riparian fauna".*[66]

The SCI did not identify any attempts to remediate the fracture networks beneath swamps and the feasibility of remediating swamps remains questionable. The Panel notes that the performance measure of minor environmental consequence for seven designated swamps at Dendrobium Mine includes provision for the *maintenance or restoration of the structural integrity of the bedrock base of any significant permanent pool or controlling rockbar within the swamp.* Further, the requirements of all performance measures may be met by avoidance, mitigation or remediation (see Table 4 in the Part 1 Report).

In its advice on Springvale Mine, the IESC commented in relation to swamps that *"there is no currently available scientific evidence to demonstrate that remediation activities are able to successfully restore the ecological and hydraulic functions of these threatened ecological communities to preimpact condition"* (IESC, 2014).[67] The OEH submission concurs that

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[62] Submission No. 26, Peabody
[63] Submission No. 30, WaterNSW
[64] Submission No. 23, Illawarra Residents for Responsible Mining
[65] Others commented on adverse impacts of efforts such as NPA Macarthur "*intrusive, damaging and unsightly, with PUR left oozing from cracks after months of work at each rockbar repair attempted.*" (Submission No. 22)
[66] Submission No. 30, WaterNSW
[67] The IESC also referred to the need to apply avoidance strategies to upstream tributaries – "*The only known strategy to reduce the risk of impact to THPSS ecological communities within the project area would be to alter the mine layout such that swamps are not undermined by longwall panels and longwalls are sufficiently removed from THPSS such that tensile and compressive strains at THPSS sites are below 0.5 mm/m and 2 mm/m respectively. This avoidance strategy should also be*

"*remediation for upland swamps is at this stage unproven*" and that until there are proven methods to re-establish baseline hydrological regimes in trial swamps rehabilitation should be considered as not feasible.[68]

In February 2013, as part of the conditions of approval for the SMP for Area 3B at Dendrobium Mine, South32 were required to develop a Swamp Research and Rehabilitation Plan (South32, 2016). The most recent version sighted by the Panel is dated August 2016 and it is understood that a workshop was held in December 2018 with key agencies to resolve issues and allow works to commence. At the time of this report the Panel is not aware of a finalised plan although the WaterNSW submission states it is "*currently facilitating access to* [South32] *to trial the application of grout (using directional drilling) beneath an affected Swamp 1B to repair the natural aquitard below the swamp*" noting that it is "*not aware whether this type of remediation has ever been attempted before, and numerous challenges confront this trial"*.[69]

5.6.1 Conclusions

The Panel concludes that:

a. Remediation efforts do not restore the entire watercourse to pre-impact conditions, but may restore water holding capacity to some rockbars and pools in streambeds.

b. Based on field observations and some submissions, the Panel considers that the PUR remediation technique used in Waratah Rivulet has been successful for restoring pool levels.

c. Currently there is no proven method to rehabilitate swamps or evidence that swamps can be remediated

5.6.2 Recommendation

23. Remediation should not be relied upon for features, including watercourses and swamps, that are highly significant or of special significance (as per the guidance provided by the Planning Assessment Commission Panels for the Metropolitan Coal Project[70] and the Bulli Seam Operations Project[71]).

5.7 OFFSETS

5.7.1 Water quantity and quality

Condition 14 of Schedule 3 of the modified Dendrobium Mine Development Consent of 8 December 2008 required that South32 provide suitable offsets for loss of water quality or loss of water flows to Water NSW storages, clearing and other ground disturbance caused by its mining operations and/or surface activities within the mining area. The Department approved the transfer of 33 ha of freehold land owned by South32 within the Metropolitan

applied to any upstream tributaries that provide a significant proportion of surface flow to THPSS. This approach is the most likely to prevent impacts to THPSS given the potential severity of impacts, difficulties in the accurate and confident prediction of impacts, and the ineffectiveness of other mitigation and management measures. Further, there is no currently available scientific evidence to demonstrate that remediation activities are able to successfully restore the ecological and hydraulic functions of these threatened ecological communities to preimpact condition." (IESC, 2014)

[68] Submission No.20, Office of Environment and Heritage

[69] Submission No. 30, WaterNSW

[70] "*'Special Significance Status' is based on an assessment of a natural feature that determines the feature to be so special that it warrants a level of consideration (and possibly protection) well beyond that accorded to others of its kind. It may be based on a rigorous assessment of scientific importance, archaeological and cultural importance, uniqueness, meeting a statutory threshold or some other identifiable value or combination of values*." (PAC, 2009)

[71] "*'Special significance' has its own definition difficulties. It is much easier to recognise at the extremes of the spectrum than in the middle"* and "*Under the current circumstances the common sense approach to significance would appear to be:…… on a case by case basis argue whether individual swamps [or associations of swamps] in a Project Area should be afforded 'special significance' status based on specific conservation reasons supported by evidence of substantial size, unusual complexity contiguous habitat, presence of EEC or threatened species, etc. In the absence of quantifiable measures and an objective threshold, conclusions about 'special significance' will be subjective. However, the practical effect of this subjectivity will decrease as the threshold is moved toward the top or the bottom of the scale."* (PAC, 2009)

Special Area to the Sydney Catchment Authority (now WaterNSW) on 18 November 2010. The offset lands were transferred to the Sydney Catchment Authority in May 2013.

At the time of issuing the modified mine development consent, Area 3A was planned to be extracted by five, 250 m wide longwall panels (LW 6 to 10), no mining layouts had been decided for Areas 3B and 3C, height of fracturing and depressurisation were not of the concern that they are today, it was not generally recognised that water inflow to Area 2 was responding to rainfall, and average daily water make was of the order of 2 ML/d. Subsequently, longwall panel width has increased to 305 m (from LW8 onwards), it is generally accepted that water inflow to Area 2 responds to rainfall, water inflow to Areas 3A and 3B also show some response to rainfall, and average daily water make has increased to just over 7.5 ML/d.[72]

Against this background, the Panel questions the adequacy of the offsets in the current mining consent in respect of loss of water flows into WaterNSW storages, recognising that the current situation was not foreseen at the time of the granting the modified consent. More appropriate offsets for the situation today may include:

- Dendrobium Mine ‘purchasing’ the water lost from the catchment that can be attributed to its mining operations. This includes that component of water take used to fill mining voids created in the overburden as a result of mining. The loss in water quantity could then be compensated for by WaterNSW allocating the financial offset to fund make-up water sources, such as through the operation of desalination plants.
- Dendrobium Mine treat the water pumped from the mine to a standard that enables it to supplement water that would otherwise be drawn from the Greater Sydney Water Catchment.

Neither of these options address long term impacts on water quantity and quality post-mine closure. If the mine can be effectively sealed such that the groundwater table can recover in decades to come and not result in the release of poor quality water to the environment, additional water will be taken from the catchment on a once off basis to fill all mine voids as part of this process. If the mine cannot be effectively sealed such that poor quality water is not discharged into the environment from overflow point/s in time to come, then water may continue to be taken from the catchment in perpetuity and there may be a need to treat water in perpetuity. These factors take on added importance as the mine footprint increases and if connective fracturing extends from the mine workings through to the surface.

The situation is somewhat different at Metropolitan Mine. Schedule 3 of the Metropolitan Mine approval includes a Performance Measure of Catchment Yield to the Woronora Reservoir, of “*Negligible reduction to the quality or quantity of water resources reaching the Woronora Reservoir”* and *“No connective cracking between the surface and the mine” (*Metropolitan Mine, Project Approval, Schedule 3, Condition 1). The Panel has no evidence to suggest that these conditions are not currently being met. Hence, provided that future mining continues to satisfy these performance measures and that when the mine is eventually sealed, water cannot escape from the mine entries or along geological discontinuities, the take of water from the catchment in the long term is not of concern.

The Panel’s assessment of the situation at Russell Vale and Wongawilli mines was constrained by these mines currently being on care and maintenance and the consequential lack of readily available historical records and loss of corporate memory.

5.7.2 Swamps

Prior to 2008, no formal instrument for biodiversity offsets existed. Recognising that many impacts of mining could not be remediated effectively, the SCI Report recommended that “*consideration should be given to the increased use within Part 3A project approvals of*

[72] As per Table 3, 7.5 ML/day refers to total mine take, not the component that is due to surface water losses.

conditions requiring environmental offsets to compensate for either predicted or non-predicted impacts on significant natural features."

Since then, the *Biodiversity Conservation Act 2016* has been introduced, which includes a statutory-based method to calculate and offset adverse environmental impacts; the 2016 addendum providing a framework to measure and address the impact of subsidence from longwall mining on upland swamps (OEH, 2016). Intended as an approach of last resort, offsets entail identifying and securing sites of equivalent environmental value.

As discussed in the Part 1 Report (§5.5) the Dendrobium Mine application for a Strategic Biodiversity Offset was approved in 2016, involving the transfer of 598 ha of land at Maddens Plains (including 140 ha of upland swamp) to the NSW National Parks Estate. Through the offset approval, impacts on, and consequences for, upland swamps due to extraction of longwalls above Dendrobium Area 3B and 3C (and impacts at the Bulli Seam Operations Project) are offset fully. The conditions of approval allow the offset to potentially be applied to meet further offsetting requirements until the conservation values of the land have been exhausted.[73]

OEH commented that the Maddens Plains Offset conforms to the like-for-like ecological rules, but the size of the offset "*was not identified or calculated using the 'consistent and scientifically-based approach'* provided by the Scheme under the Act; the offset predating the introduction of the calculator in 2016.[74] Others questioned whether the offset conformed to the 'like-for-like' rules since it was outside of the catchment and therefore the impacts on the Special Areas have not been properly considered.

The occurrence of rare and unique ecological communities, such as coastal upland swamps is limited, and the potential of seeking 'like-for-like' equivalents may prove challenging. OEH commented that "*mine plans may need to be modified to achieve predictions that result in impact to upland swamps".*[75] Commenting that the new offset policy "*is extremely conservative and assumes total loss of the entire swamp based on changes to the groundwater system within swamps*", the NSW Minerals Council expressed concern that it could be *"difficult to secure offset arrangements that comply with the policy".*[76]

5.7.3 Conclusions

a. Consent conditions for Dendrobium Mine issued in 2008 in relation to offsetting impacts on water quality do not appear to have foreseen the scale of impacts occurring today and into the future and, therefore, are considered by the Panel to be inadequate.

b. More appropriate offsets for the situation today for all mining operations may include:

   i. 'purchasing' the water lost from the catchment that can be attributed to mining operations. This includes that component of water take used to fill mining voids created in the overburden as a result of mining. The loss in water quantity could then be compensated for by WaterNSW allocating the financial offset to fund make-up water sources, such as through the operation of desalination plants.

   ii. treating the water pumped from the mine to a standard that enables it to supplement water that would otherwise be drawn from the Greater Sydney Water Catchment.

[73] Term of approval 15 (Strategic Biodiversity Offset state in part "*If the Secretary has issued a statement under this condition, the Applicant can rely on that statement and the residual conservation values that the land subject to the statement may hold, to meet further offsetting requirement(s) that may be required under this consent or the project approval for the Bulli Seam Operations Project (08_0150). The Secretary's statement under this condition can be relied on a number of times in respect of the same land until all of the conservation values of the land the subject of the Secretary's statement have been relied upon to meet offsetting requirements under this consent or the approval for the Bulli Seam Operations Project (08_0150)*."

[74] Submission No.20, Office of Environment and Heritage

[75] Submission No.20, Office of Environment and Heritage

[76] Submission No.27, NSW Minerals Council

c. Neither of these options address long term impacts on water quantity and quality post-mine closure.

d. Provided that future mining at Metropolitan Mine continues to satisfy the performance measures and that when the mine is eventually sealed, water cannot escape from the mine entries or along geological discontinuities, the take of water from the catchment is currently of no immediate or long term concern.

e. Consent conditions for Dendrobium Mine issued in 2008 in relation to offsetting impacts on swamps do not appear to have foreseen the scale of impacts occurring today but have been subsequently addressed by a Strategic Biodiversity Offset approved in 2016.

5.7.4 Recommendations

24. There is a need to update provisions for offsetting water loss from the catchment resulting from all mining operations.

25. Provisions for offsetting impacts on water quantify and water quality associated with mining operations in the catchment need to give careful consideration to long term impacts, post-mine closure.

26. Mine planning today needs to take into account impacts that may arise in the long term, post-mine closure.

5.8 REHABILIATION AND MINE CLOSURE PLANNING

The need for mine planning to be give more detailed consideration to mining induced impacts in the long term, post-mine closure, has been identified a number of times in this report.

The focus of the SCI in respect of water was primarily on the short-term implications of mining for water flow in swamps and watercourses. Matters that it did not consider in any detail or at all and which are now important include surface and groundwater behaviour and management in the long term and how this may be influenced by decisions being made today. Consideration already needs to be given to the implications of these decisions for ultimate mine rehabilitation and closure.

Mine rehabilitation and closure planning is the process whereby an operational mine is transformed to a completed state that permits the mining lease to be relinquished and responsibility for the site to be accepted by the next land user. The overall objective of mine completion is to prevent or minimise adverse long-term environmental, physical, social and economic impacts, and to create a stable landform suitable for agreed subsequent land use (DITR, 2006). Ideally, the site should be left in a self-sustaining and self-managing state and not impose a long term detrimental legacy on future generations (Galvin, 2017a).

Historically, conditions attached to mining leases contained few, if any, provisions for the ultimate closure and rehabilitation of mining operations. This situation started to change significantly in Australia at around the time of the SCI, with the production of a range of mine rehabilitation and closure guidelines, supported by technical advices relating to specific aspects of mine closure and rehabilitation (for example, ANZMEC and MCA (2000); DITR (2006); ICMM (2008); NSW Trade & Investment (2012). Figure 14 and Figure 15 are reproduced from ICMM (2008)) and show the recommended conceptual planning process for mine closure. These are put into context in respect of potential long term mining impacts in the Special Areas by reference to Figure 7.

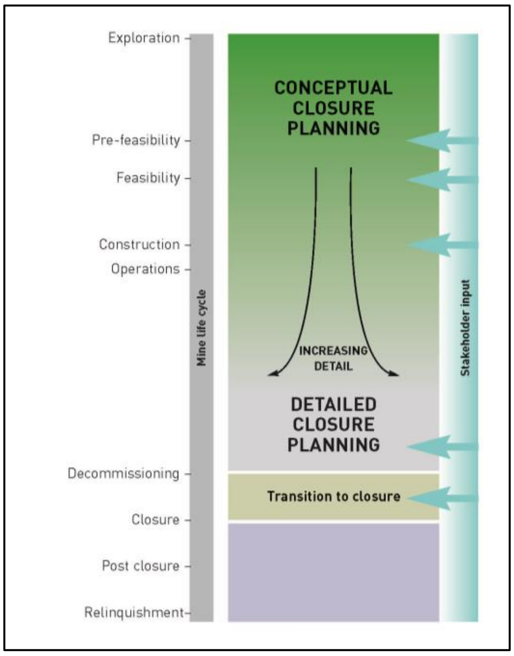

Figure 14: Process for planning for closure
Source: ICMM (2008)

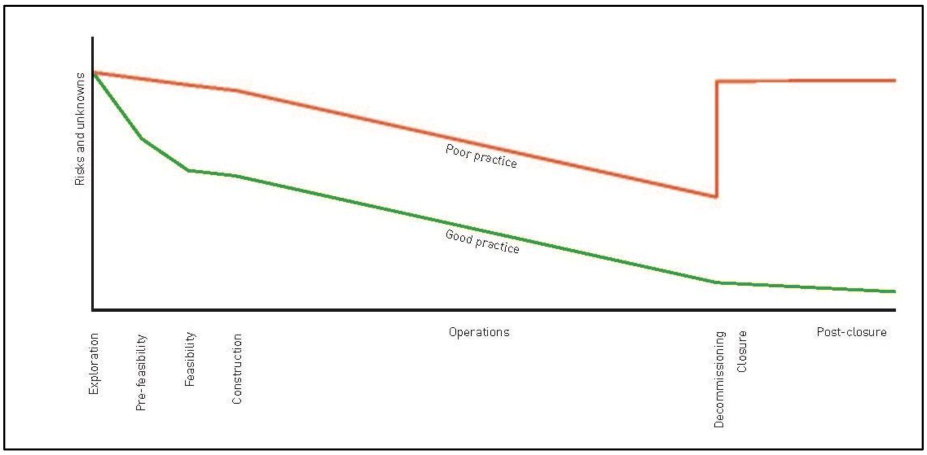

Figure 15: The importance of good practice, experience and planning for reducing closure unknowns and risks
Source: ICMM (2008)

The situation in NSW as at around 2008 is reflected in:

- Neither the SCI, MCP PAC or BSO PAC considered the implications of mining impacts on rehabilitation and mine closure planning.
- The 2008 consent conditions for Dendrobium Mine required the preparation of a Rehabilitation Management Plan and also a Mine Closure Plan, but these were stipulated as elements of a Landscape Management Plan. In turn, the requirements for each of these elements had no focus on the implications of current mining activities for rehabilitation and mine closure planning, other than a requirement for the Rehabilitation Management Plan to include *any measure to ensure that abandoned mine workings do not impact on stored waters or dams.*
- The 2009 consent conditions for Metropolitan Mine make no mention of planning for mine closure other than a rehabilitation objective of: *Minimise the adverse socio-economic effects associated with mine closure including the reduction in local and regional employment*

5.8.1 Conclusion

The Panel concludes that:

a. Mining proposals need to specifically address the long term implications of mining for rehabilitation and mine closure planning.

b. Further work is needed to better understand and quantify potential impacts on water quantity and quality arising from current and historical mining in the Special Areas. The scope and scale of work should be subject to consideration by relevant agencies and stakeholders, with key considerations likely to be:

    i. the dimensions of mine workings and their relationship to the depth of mining as a basis for estimating the extent of connective fracturing through to the surface.

    ii. the potential for interaction between multiseam workings within a mine

    iii. the potential for interaction between workings in different mines

    iv. current location of water outflow from each mine, which may be through an adjacent mine

    v. the relative contributions and magnitudes of the various potential sources of water inflow into mine workings

    vi. current quantity and quality of water outflow

    vii. the current state of sealing of each mine

    viii. the potential to effectively seal mine workings

    ix. the long term implications of mine sealing, including causing water to be diverted into adjacent mines as water levels rise within a sealed mine and to surface locations through fracture networks that daylight.

    x. the time period leading up to long term implications becoming apparent

5.8.2 Recommendations

27. A study be undertaken to better understand and quantify the potential impacts of historic and current mining for long-term cumulative impacts on water quantity and quality in the Greater Sydney Water Catchment, for the purpose of properly informing mine design, mine rehabilitation and closure planning, planning assessments, offsets and rehabilitation bonds.

28. SEARs and any conditions of consent should include a focus on the long term implications of mining proposals for rehabilitation and mine closure planning.

29. Impact assessments associated with proposals for mining in the Special Areas need to include detailed consideration of rehabilitation and mine closure planning that extends beyond management of the landscape.

5.9 GOVERNMENT ACCESS TO EXPERTISE

The Initial Report commented on the need for Government to have a sustainable mechanism for accessing objective expert advice when assessing mining applications and that applications need to be supported by robust, independent peer review and/or demonstrated history of reliability when applications are submitted to government.

The Report recommended that "*in the longer term, arrangements should be made to ensure that government has access to appropriate and independent expert advice when assessing mining proposals and performance outcomes".*

This recommendation led to considerable comment in consultations and submissions to the Panel from both industry and community groups, including:

- the need for experts to be independent, some suggesting that experts should have never worked for the mining industry; should be appointed by government but paid for by the mining company as part of their application
- if an expert panel becomes part of the process, there is a need to improve transparency around the timing and timeframes for advice
- a pool of experts should be developed with a range of skills and knowledge that can be drawn upon for advice, noting that the nature of some issues may require local knowledge and experience that cannot be obtained from international experts and consultants.

The Panel appreciates community concerns about industry exposure and potential conflicts of interest. However, appropriate expertise in many cases cannot be obtained without direct involvement or experience in the industry. This is especially true in the Special Areas given the complex and relatively unique combination of factors that need careful assessment.

5.9.1 Recommendation

30. Government needs to establish a sustainable mechanism for accessing objective and timely expert advice when assessing mining applications and performance outcomes and this mechanism needs to be supported by probity guidelines that have regard to experts having worked in the mining industry in order to gain their expertise.

5.10 INCREMENTAL APPROVAL PROCESS

The SCI was of the opinion that the decision making framework provided by reforms to the EP&A Act, together with the *Mining Act 1992*, provided a good foundation for the future management of coal mining subsidence in the Southern Coalfield and elsewhere in the State.[77] The SCI concluded these reforms provide a process through which performance standards and environmental outcomes can be developed following scientific studies and stakeholder input and then set within a robust approval document. The project approval process under the EP&A Act is a case-by-case process that recognises the variability of sites and remains flexible within the growing body of knowledge regarding subsidence effects, impacts and consequences.

The SCI acknowledged that environmental impact assessment, performed at the application stage for project approval under the EP&A Act, should be the primary tool used to set the envelope of all acceptable environmental impacts for mining projects. Once the expected outcomes are defined and an underground mining project has project approval, the essential role of the EPs should be to ensure that the risk of impacts remains within that which was assessed and approved. The EP should be a management document - plans should be prepared to demonstrate how the required outcomes will be achieved, what monitoring will occur and how deviations and contingencies will be addressed.

Subsequently, the MCP PAC reported that:

> *"The Panel has made its findings and recommendations based on the information available to it. In many instances the Panel has noted serious inadequacies in this information as a basis for making unequivocal recommendations. Consequently, many of the recommendations are based on suggestions that further studies or reviews be conducted to confirm that the position adopted by the Panel is sound in the longer term. Whilst this approach may allow mining to proceed in the short term, there is a real possibility that a modified mine management regime will be required as the information is acquired and reviewed."*

[77] p. 111

"This approach will also place much greater reliance on the SMPs than the [SCI] Panel considers desirable. Therefore, it will be important that a substantial level of rigour is applied to the SMP process to ensure that the information on which to base these plans is produced in a timely fashion and to the required standard."[78]

In the Initial Report (now Part 1 Report), the Panel stated that the knowledge base regarding mining-induced subsidence and its impacts on groundwater and surface water continues to grow. In some cases, these advances have identified aspects not appreciated at the time of mine approval and may require the originally proposed mine layouts to be revised in order to comply with performance measures.[79] It went on to endorse Department's approach of approving longwall panels at Dendrobium and Metropolitan mines on an incremental basis in the light of existing and emerging information and knowledge gaps that have the potential to jeopardised compliance with performance measures.

Industry stakeholders have expressed concerns regarding the incremental approvals process.[80] Factors cited included operational discontinuity associated with the timing and short-term nature of secondary approvals, reported as undermining investment certainty and long-term viability of projects.

The Panel appreciates these concerns. It is cognisant of the significant capital expenditure associated with operating underground coal mines and of the criticality of timely mining approval to facilitate efficient longwall mining, especially given the lead time required to block out future mining panels. The Panel is also aware that many other longwall operations in NSW are not subjected to such frequent and short term incremental approvals.

However, the reality is that longwall mines operating in the Southern Coalfield, and especially in the Special Areas, are operating in a complex and relatively unique combination of geotechnical, hydrogeological and environmental conditions, with an incomplete design knowledge base that is still evolving and which may never be complete, and with high potential consequences attached to some aspects of deficient mine design. A number of examples of these aspects are contained in the Part 1 Report and this report and include:

- limitations in the methodologies for predicting for valley closure and its impacts on watercourses and swamps
- emerging evidence and confirmation of surface to seam hydraulic connections over some areas of the Dendrobium Mine workings
- under-prediction of vertical surface displacement by around 30% when commencing to mine in Area 3B at Dendrobium Mine
- swamp impacts at Dendrobium Mine in excess of predictions, necessitating the invoking of offsets
- valley closure impacts in excess of predictions at Metropolitan Mine, resulting in a exceedance of approval conditions and a need to modify the mine design.

Due diligence in risk management necessitates incremental approvals and external expert review at this point in time as illustrated by the following summary example (Table 5), which demonstrates the applicability and success of an adaptive management approach supported with external expert review in current circumstances.

[78] Page 134
[79] Page 55
[80] This includes submissions from Peabody (No.26), South32 (No.29) and the NSW Minerals Council (No.27).

Table 5: Case Study: Metropolitan Mine – Approval and extraction of LW 303

Date	Action
11/16	Extraction Plan submitted for LW 301 to LW 303. The dimensions of the longwall panels were greater than those assessed by PAC.
11/5/17	The Department approved extraction of LW 301 and LW 302 at increased dimensions.
6/7/18	Approval sought for LW 303 but with panel length reduced by 98 m to take account of anomalous valley closure results and exceedance of approval conditions for impacts on Eastern Tributary.
17/7/18	The Department requests Panel to review Extraction Plan
13/8/18	Panel questions if the reduction in panel length of 98 m is sufficient to ensure compliance with approval conditions and it seeks clarification on a range of issues.
19/9/18	Updated Extraction Plan for LW 303 submitted
6/11/18	Panel advise that panel length should be shortened by a further 430 m in order to achieve approved performance measures
8/11/18	The Department grants conditional approval for LW 303, based on it stopping the longwall at least 450 m short
5/2/19	Approval sought to increase panel length by 182 m based on an adaptive management plan
7/3/19	The Department requests panel to review application
21/3/19	Panel raises a number of questions, concluding that an increase in longwall panel length is technically feasible, and if adaptive management plans are to form the basis for approving an increase in extractable length, are subject to further development and justification
16/5/19	LW 303 stopped after only additional ~50 m of retreat. Final panel length based on adaptive management some 500 m shorter than proposed in original LW 301 to LW 303 Extraction Plan

5.10.1 Conclusions

The Panel concludes that:

a. Incremental approvals at less than 3 to 5 yearly intervals for longwall mines are undesirable from a business perspective

b. However, longwall mines operating in the Southern Coalfield, and especially in the Special Areas, are operating in a complex and relatively unique combination of geotechnical, hydrogeological and environmental conditions, with an incomplete design knowledge base that is still evolving and which may never be complete, and with high potential consequences attached to some aspects of deficient mine design

c. Therefore, given the complexity and highly technical nature of issues associated with mining in the Special Areas, uncertainties in knowledge bases, performance outcomes to date and the potential consequences of unplanned outcomes, due diligence in risk management necessitates incremental approvals and external expert review at this point in time.

6 MAJOR CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

6.1.1 Subsidence effects, impacts and consequences on water supply

- Subsidence impacts and consequences for groundwater, surface water and swamps have assumed a higher profile since the SCI.
- There have been significant improvements since 2008 in integrating the various scientific studies and disciplines involved in subsidence impact assessment and management, but there is still some way to go.
- Height of fracturing leading to groundwater depressurisation has emerged as a critical issue since the SCI.
- Effects resulting from conventional surface subsidence behaviour and their impacts are well understood and reasonably predictable. Nevertheless, management systems still need to make provisions for those occasions, albeit rare, where subsidence effects are significantly under-predicted.
- Despite substantial research, there has been little advance in the reliable prediction of non-conventional subsidence effects and impacts. There are considerable disparities between predicted and measured valley closures, reflecting the complex and site specific nature of ground responses to mining in Southern Coalfield conditions. The gaps in the knowledge base continue to be managed on the basis of designing to recorded worst case outcomes.
- There is increasing recognition of the potential for geological discontinuities to act as or become conduits for groundwater flow.
- Since the SCI, likelihood relationships for the Southern Coalfield have been derived between predicted total valley closure and the proportion of fractured rockbars that control pool water levels. However, this coalfield-wide approach can mask site specific behaviours, does not provide insight into the scale and distribution of the consequences associated with the fracturing and loss of water retention properties of rockbars, and does not address the potential for water loss from pools formed behind boulder fields. Nor does it consider water loss from beneath the boulder fields themselves. Hence, the prediction of impacts on watercourses on the basis of only impacted rockbars is an incomplete process.
- The idea that a performance measure of minor will be satisfied in situations where total valley closure is predicted to be less than 200 mm or where less than a certain percentage of pools lose their water retaining capacity is questionable in circumstances other than when consent conditions make provision for meeting the requirements of performance measures by avoidance, mitigation or remediation.
- Dendrobium Mine was approved almost two decades ago and its consent conditions, due to expire in 2030, are not fully representative of contemporary consent conditions, notwithstanding that ongoing mining is regulated through contemporary SMP approvals.
- Since the SCI, there has been a progressive move away from specifying performance measures in qualified terms, and towards more quantifiable terms. There are still opportunities for government to improve the effectiveness of performance measures, especially for watercourses and swamps, by specifying them in terms that are less ambiguous and more quantifiable and measurable.
- Going forward, there is a need to consider the potential for regional movement on

bedding planes and the practicality of specifying water quality and iron staining as components of performance measure for only a proportion (or percentage) of the length of a stream, since these types of impacts may not be able to be contained within a close distance to the mining footprint.

6.1.2 Groundwater and surface water

- The performance measures applied to the Dendrobium Mine do not sufficiently manage risks of surface water losses due to depressurisation. This is due to past limitations in knowledge about height of fracturing and potential cumulative impacts on pool levels and surface water losses.
- In terms of general approach, flow loss TARPs are applied consistently across the four mines; however, there are significant variations in the details of how triggers are defined and assessed. There is no clear reason for these variations.
- A considerable reduction in short term and long term environmental impacts may be realised by preventing the height of free drainage in the Special Areas from intersecting the surface either directly or indirectly by interaction with surface fracture networks.
- This may be achievable beyond the Marginal Zones around reservoirs by working to mining dimensions that are not as conservative as those that apply to mining under the reservoirs.
- Preventing the height of free drainage from reaching the surface does not eliminate the risk of surface water and swamps continuing to be impacted by conventional and non-conventional subsidence but it is likely to result in a reduction in the scale of many of these impacts.
- The long term nature of cumulative impacts and their consequences for water quantity, water quality and swamp ecology in the catchment after mine closure have received limited attention in past mining proposals.
- Following mine closure, the issues expand to include not only natural water inflow from the surface to mine workings but also the potential for water to outflow from the mine voids and fracture networks back to the surface as the mine fills, the quantity and quality of this outflow, whether it can report back into the catchment, and the consequences for water quantity and quality in the catchment if it does.
- Much depends on whether it is physically possible to confine water in the mine and the extent to which the water table can be reestablished in order to reverse depressurisation.
- Options for best managing cumulative impacts on water quantity and quality in the long term may include not attempting to restore the water table in defunct mines but, instead, allowing water to discharge from mine entries and treating it to a standard sufficient for it to replace water that would otherwise be supplied from the catchment. Further investigation is required into how this option could be factored into closure planning if it needs to be funded and maintained in perpetuity.
- There is an increasing body of evidence that mining in the Metropolitan Special Area has resulted and continues to result in losses of water from the Greater Sydney water supply system. The losses include surface water diversions into the mines, leakage from reservoirs into the mines and loss of baseflow in watercourses due to groundwater depressurisation. Presenting a definitive recent loss rate for the Metropolitan Special Area is complex because the available estimates correspond to different time periods and/or catchment areas, and no estimates are available for most historical mines.
- Available estimates show that the upper limit of recent loss rate totalled over the Dendrobium, Wongawilli and Russell Vale mines is an average of 8 ML/day and for the Dendrobium Mine alone is less than 5 ML/day. Loss rates from both Dendrobium and

Metropolitan mines are expected to increase as the area of excavated coal seams increase. Loss rates at Dendrobium Mine vary over time depending on rainfall.

- These losses are low compared to other components of Greater Sydney's supply and demand. For example, 8 ML/day compares to the Sydney Desalination Plant capacity of approximately 250 ML/day and estimated leaks from the Greater Sydney supply infrastructure of approximately 130 ML/day.
- Losses of water from the Woronora Special Area due to mining impacts associated with Metropolitan Mine are negligible, with a water make between 2009 and 2017 that has averaged at 0.09 ML/day and, with the exception of May 2011, a 20 day average water make below 0.5 ML/day.
- However, the significance of different levels of loss in terms of reductions in security yield of the Greater Sydney water supply system and necessary compensatory investments or other management actions are unknown. WaterNSW is developing an approach to address this.
- The DSC derived a tolerable reservoir storage loss limit of 1 ML/day for use in assessing applications to undertake mining within a DSC Notification Area. The recent attempts to apply this limit for other purposes, such as cumulative losses, have no clear and up-to-date objective basis.
- It is simply not feasible in current circumstances for the Panel to reasonably reliably quantify long term cumulative impacts of past and current mining operations on water quantity in the catchment.
- Considerable progress has been made in implementing groundwater and surface water models to help quantify water losses from the catchments affected by the Metropolitan and Dendrobium mines. Further refinements to groundwater models are necessary to improve accuracy.
- The Panel does not recommend development of a new regional scale model covering the Special Areas at least until the knowledge base is substantially developed, having regard to the challenges identified in this Report.

6.1.3 Swamps

- Since 2008 the collection of monitoring data supported by a substantial body of research has improved understanding of the impacts and consequences of longwall mining for swamps.
- Nevertheless, the integrated monitoring and modelling needed to understand the contribution of swamps to baseflows continues to be extremely limited and no accurate water balance is available for any swamp in the Southern Coalfield.
- It is now established that longwall mining directly under swamps in the Southern Coalfield can result in significant changes to swamp hydrology and redirection of surface runoff, which the Panel considers are very likely irreversible.
- While impacts on the swamps themselves and on the streams exiting from them are evident, it remains the case that there is no strong evidence to date of consequences of swamp impacts on catchment-scale water supplies.
- When shallow groundwater levels in a swamp decline, soil moisture levels also decline, with a lag time of weeks or months.
- Quantifying the consequences of these changes for flows in exit streams requires the development of water balance models of the swamps.
- Despite decades of monitoring, mining-induced changes to upland swamp vegetation communities are still not able to be clearly differentiated from natural changes.

- Vegetation change assessment does not provide a clear and timely measure of possible changes in ecosystem functionality of the upland swamps. While changes in methodology, such as using targeted obligate swamp-dependent species (either plants or animals) may improve assessment, the decadal nature of many changes remains a barrier to distinguishing between mining-induced variations and natural variations.
- It appears that there has been little work undertaken in the Special Areas to measure mining impacts on swamp fauna, including obligate swamp species.
- There is very limited, if any, scope for remediating fracture networks beneath swamps. Therefore, in circumstances where it is difficult, if not impossible, to design a viable mining layout that avoids impacting swamps and mining is to proceed, there is little option other than to consider offsets as compensation for the consequences of negative environmental impacts on swamps.

6.1.4 Reverse Onus of Proof

- The concept of Reverse Onus of Proof as espoused in the SCI Report is unworkable.
- The concept of Reverse Onus of Proof has been superseded in practice by the requirement for a Proponent demonstrate the reasonableness (or overall merit) of its proposals in relation to the significant natural features that may be exposed to subsidence impacts, thereby enabling the decision-maker to assess reasonableness (or merit) in the context of the importance of the features, the predicted risks and any management options for those risks.

6.1.5 Risk management zones

- The concept and intent of RMZs is reflected in current SEARs, albeit that the mechanism which gives effect to the concept is not prescribed to the extent proposed by the SCI and PAC assessment panels a decade ago.
- It should be established if there are circumstances where the size of RMZs, or their conceptual equivalent, need to be increased for risk assessment purposes to properly account for the consequences of groundwater depressurisation.

6.1.6 Cumulative impacts

- The development of open databases could substantially benefit:
  - quantifying regional cumulative impacts assessment, both in the short term and the long term
  - transparent and objective assessment of mining proposals
  - mine closure planning and post-closure management

6.1.7 Remediation

- Remediation efforts do not restore the entire watercourse to pre-impact conditions, but may restore water holding capacity to some rockbars and pools in streambeds.
- Based on field observations and some submissions, the Panel considers that the PUR remediation technique used in Waratah Rivulet has been successful for restoring pool levels.
- Currently there is no proven method to rehabilitate swamps or evidence that swamps can be remediated

6.1.8 Offsets

- Consent conditions for Dendrobium Mine issued in 2008 in relation to offsetting impacts on water quality do not appear to have foreseen the scale of impacts occurring today and into the future and, therefore, are considered by the Panel to be inadequate.

- More appropriate offsets for the situation today for all mining operations may include:
    - ‘purchasing’ the water lost from the catchment that can be attributed to mining operations. This includes that component of water take used to fill mining voids created in the overburden as a result of mining. The loss in water quantity could then be compensated for by WaterNSW allocating the financial offset to fund make-up water sources, such as through the operation of desalination plants.
    - treating the water pumped from the mine to a standard that enables it to supplement water that would otherwise be drawn from the Greater Sydney Water Catchment.
- Neither of these options address long term impacts on water quantity and quality post-mine closure.
- Provided that future mining at Metropolitan Mine continues to satisfy the performance measures and that when the mine is eventually sealed, water cannot escape from the mine entries or along geological discontinuities, the take of water from the catchment is currently of no immediate or long term concern.
- Consent conditions for Dendrobium Mine issued in 2008 in relation to offsetting impacts on swamps do not appear to have foreseen the scale of impacts occurring today but have been subsequently addressed by a Strategic Biodiversity Offset approved in 2016.

6.1.9 Rehabilitation and mine closure planning

- Mining proposals need to specifically address the long term implications of mining for rehabilitation and mine closure planning.
- Further work is needed to better understand and quantify potential impacts on water quantity and quality arising from current and historical mining in the Special Areas. The scope and scale of work should be subject to consideration by relevant agencies and stakeholders, with key considerations likely to be:
    - the dimensions of mine workings and their relationship to the depth of mining as a basis for estimating the extent of connective fracturing through to the surface.
    - the potential for interaction between multiseam workings within a mine
    - the potential for interaction between workings in different mines
    - current location of water outflow from each mine, which may be through an adjacent mine
    - the relative contributions and magnitudes of the various potential sources of water inflow into mine workings
    - current quantity and quality of water outflow
    - the current state of sealing of each mine
    - the potential to effectively seal mine workings
    - the long term implications of mine sealing, including causing water to be diverted into adjacent mines as water levels rise within a sealed mine and to surface locations through fracture networks that daylight.
    - the time period leading up to long term implications becoming apparent.

6.1.10 Incremental approval process

- Incremental approvals at less than 3 to 5 yearly intervals for longwall mines are undesirable from a business perspective

- However, longwall mines operating in the Southern Coalfield, and especially in the Special Areas, are operating in a complex and relatively unique combination of geotechnical, hydrogeological and environmental conditions, with an incomplete design knowledge base that is still evolving and which may never be complete, and with high potential consequences attached to some aspects of deficient mine design
- Therefore, given the complexity and highly technical nature of issues associated with mining in the Special Areas, uncertainties in knowledge bases, performance outcomes to date and the potential consequences of unplanned outcomes, due diligence in risk management necessitates incremental approvals and external expert review at this point in time.

6.2 RECOMMENDATIONS

6.2.1 Subsidence effects, impacts and consequences on water supply

- The concept of subsidence effects, subsidence impacts and subsidence consequences should continue to be embedded in mining assessment processes
- There is a need for a higher focus on the assessment of regional impacts and consequences associated with groundwater depressurisation, including if and how far these impacts and consequences might extend beyond the mining footprint.
- Research is required into:
    - quantifying the height of complete drainage above mine workings
    - the reliability of geomechanical modelling of rock fracturing and fluid flow for informing the calibration of groundwater models and, thus, also replacing the use of the Tammetta and/or Ditton equations
    - establishing the potential for regional movement on bedding planes and the potential consequences that this may have, especially in the vicinity of water storages.
- Management plans need to make provision for the early detection and control of the elevated risk that variance between predicted and measured subsidence effects, both conventional and non-conventional, when mining in areas sensitive to subsidence impacts, such as the Greater Sydney Water Catchment. This is especially the case when utilising longwall mining since the method is inflexible to immediate changes in mine layout to address of deviations from predictions.
- Impact assessments for watercourses should consider not only rockbars and the pools behind them, but all features along the full lengths of watercourses.
- The Department should review the practicality of specifying water quality and iron staining as components of performance measure for only a proportion (or percentage) of the length of a watercourse.

6.2.2 Groundwater and surface water

- All future mine approvals should include performance measures that are objective and can more precisely determine the cumulative impacts and consequences of a mine project progression. Performance measures should include changes in pressure and/or pressure gradients where these have the potential to impact on surface water losses.
- When consent conditions make provision for meeting the requirements of performance measures by avoidance, mitigation or remediation, they need to be quite specific about the scope of attributes that have to be avoided, mitigated or remediated and the verification standards that avoidance, mitigation and remediation measures have to satisfy.

- TARP triggers for surface and groundwater should be based on meaningful indicators developed in consultation with relevant agencies and authorities with oversight and regulatory responsibilities for mining
- Uncertainty analysis of groundwater and surface water models should follow the uncertainty analysis workflow recommended by the IESC.
- Independent expert peer review should become a more regular part of the groundwater and surface water model assessment process
- An inter-agency working group should be set up with the task of identifying acceptable levels of surface water loss due to mining.
- Additional flow gauges and improvements to existing flow gauges should continue to be undertaken selectively by mining companies in consultation with WaterNSW, or by WaterNSW (with potential financing from the companies) including aiming for at least 4 years of baseline flow data at sites that are important for quantifying water supplies including future performance measure sites and control sites.
- Monitoring of contaminant concentrations should be integrated with flow monitoring at operational mines to support calculation of contaminant loads at the main inputs to reservoirs and other key locations and to improve understanding of future contaminant loading risks. Relevant contaminants should be agreed between primary stakeholders.
- Government should ensure that sufficient water entitlements are retained by mines operating in the Special Areas to cover surface water losses resulting from mining-induced effects.

6.2.3 Swamps

- Future swamp monitoring and modelling programs should be designed to:
    - provide a hydrological balance for representative swamps, sufficient to identify any mining-induced changes in soil moisture and in baseflow down the exit stream; and to provide vertical leakage rates as inputs to groundwater models, in order to quantify how much of the leakage is diverted back into the catchment or elsewhere.
    - link any changes in swamp vegetation to changes in water table position, soil moisture content and soil organic carbon content.
    - identify the presence of and any changes in obligate swamp fauna such as the giant dragonfly (*Petalura gigantea).*
- Government organisations, especially WaterNSW, should support and/or carry out independent research (possibly on a cost recovery basis from the mining sector) to provide regional information on swamp hydrology and ecology. In particular, continuation of monitoring at sites where there is a substantial basis of data should be a priority.
- Annual performance reports, end-of-panel reports and reports on studies required by development consent conditions, should:
    - integrate hydrological and ecological impact and consequence assessments
    - include discussion of the inter-related changes in hydrological and ecological consequences for swamps, rather than having only discrete chapters on each
    - include results for the entire period of monitoring, rather than just the previous year, that should be assessed, not only for the current mining area but for previous mining domains.

6.2.4 Reverse onus of proof

- The concept of Reverse Onus of Proof should be discarded.

6.2.5 Cumulative impacts

- Environmental data from mine companies should be housed in a centralised data portal, such as the SEED portal, prioritised according to its value in assessing cumulative impacts of concern.

6.2.6 Remediation

- Remediation should not be relied upon for features, including watercourses and swamps, that are highly significant or of special significance (as per the guidance provided by the Planning Assessment Commission Panels for the Metropolitan Coal Project and the Bulli Seam Operations Project).

6.2.7 Offsets

- There is a need to update provisions for offsetting water loss from the catchment resulting from all mining operations.
- Provisions for offsetting impacts on water quantify and water quality associated with mining operations in the catchment need to give careful consideration to long term impacts, post-mine closure.

6.2.8 Rehabilitation and mine closure planning

- A study be undertaken to better understand and quantify the potential impacts of historic and current mining for long-term cumulative impacts on water quantity and quality in the Greater Sydney Water Catchment, for the purpose of properly informing mine design, mine rehabilitation and closure planning, planning assessments, offsets and rehabilitation bonds.
- SEARs and any conditions of consent should include a focus on the long term implications of mining proposals for rehabilitation and mine closure planning.
- Impact assessments associated with proposals for mining in the Special Areas need to include detailed consideration of rehabilitation and mine closure planning that extends beyond management of the landscape.

6.2.9 Government access to expertise

- Government needs to establish a sustainable mechanism for accessing objective and timely expert advice when assessing mining applications and performance outcomes and this mechanism needs to be supported by probity guidelines that have regard to experts having worked in the mining industry in order to gain their expertise.

ACRONYMS

Table 6: Acronyms

Acronym	Complete Term
3D	Three dimensional
ACARP	ACARP – formerly Australian Coal Association Research Program
AWBM	Australian Water Balance Model
BSO	Bulli Seam Operations
CRR	Cumulative Rainfall Residual
CSE	NSW Chief Scientist & Engineer
CSG	Coal Seam Gas
DGR	Director-General's Requirements
DGS	Ditton Geotechnical Services
DPE	Department of Planning and Environment (now DPIE)
DPIE	Department of Planning, Industry and Environment ('the Department')
DSC	Dam Safety Committee (transitioning to Dam Safety NSW)
EA	Environmental Assessment
EIS	Environmental Impact Statement
EOP	End of Panel
EP	Extraction Plan
EP&A Act	*Environmental Planning and Assessment Act 1979*
FSL	Full Storage Level
GL	Giga Litres
GW	Groundwater
IESC	Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development
IPM	Incremental Profile Method
LW	Longwall
MCP	Metropolitan Coal Project
ML	Mining Lease or Mega Litres
MSEC	Mine Subsidence Engineering Consultants
NRAR	National Resources Access Regulator
NSW	New South Wales
NSW LEC	New South Wales Land and Environment Court
OEH	Office of Environment and Heritage (environmental functions now Biodiversity & Conservation in Environment, Energy & Science, DPIE)
PAC	Planning Assessment Commission (now the Independent Planning Commission)
PSM	PSM – formerly Pells Sullivan Meynink
PUR	Polyurethane Resin
RMZs	Risk Management Zones
SCI	2008 Southern Coalfield Inquiry (*Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield – Strategic Review)*
SEARs	Secretary's Environmental Assessment Requirements (previously Director–General's Requirements or DGRs)
SEED	Sharing and Enabling Environmental Data Portal
SMP	Subsidence Management Plan
SSD	State Significant Development
TARP	Trigger Action Response Plan
THPSS	Temperate Highland Peat Swamps on Sandstone
TOR	Terms of Reference
WC	Wongawilli Creek
WWL	Wongawilli Creek Lower

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APPENDICES

APPENDIX 1: TERMS OF REFERENCE

Purpose

The Independent Expert Panel has been established to provide informed expert advice to the Department of Planning and Environment on the impact of mining activities in the Greater Sydney Water Catchment Special Areas, with a particular focus on risks to the quantity of water in the Catchment.

Advice will include, but is not confined to risks to the total water quantity and holding capacity of surface and groundwater systems, including swamps and reservoirs, and the types and reliabilities of methodologies used to predict, monitor, assess and report on mining effects, impacts and consequences.

As needed, the Independent Expert Panel will provide a source of expert advice to the Department of Planning and Environment on mining applications, including monitoring and management plans.

Scope of Work

The Independent Expert Panel will:

1. **Undertake an initial review and report on specific coal mining activities at the Metropolitan and Dendrobium coal mines in the Greater Sydney Water Catchment Special Areas**, including:
    a. A review of the findings and recommendations of studies and reports deemed appropriate by the Panel, including but not confined to the reports:
        i. *Height of Cracking - Area 3B*, prepared by PSM, dated 16 March 2017
        ii. *2016 Audit of the Sydney Drinking Water Catchment*, prepared by Alluvium, dated June 2017.
    b. A review of the types and reliability of prediction, monitoring and response methodologies (including mitigation, remediation and rehabilitation) currently used for assessing and managing the effects, impacts and consequences of mining activities at the Metropolitan and Dendrobium coal mines as they relate to water quantity, including having regard to historical data and performance.
    c. Provide advice and recommendations on measures required to improve approaches to prediction, monitoring, responses and reporting at the Metropolitan and Dendrobium coal mines, including having regard to cumulative risks posed to the quantity of drinking water available in the Greater Sydney Water Catchment Special Areas.
    d. Based on the outcomes TOR 1(a) to 1(c), provide advice to Government on how to respond to the findings and recommendations of reports reviewed as part of TOR 1a.
    e. In developing its advice, the Panel will meet, undertake site visits, seek information and data, and consult as needed.
    f. In delivering its report, the Panel will provide comment on and make observations or recommendations about any information or factors the Panel believes relevant; or further work that should be undertaken.
    g. A progress update on the report is to be delivered no later than 30 April 2018 and the report is to be delivered no later than 31 July 2018.

    NOTE: the reporting date was subsequently been extended to 12 November 2018.

2. **Undertake a review of current coal mining in the Greater Sydney Water Catchment Special Areas with a particular focus on risks to the quantity of water available, the environmental consequences for swamps and the issue of cumulative impacts**, including:
    a. A review and update of the findings of the *2008 Southern Coalfield Inquiry (Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield - Strategic Review)* for mining operations at the Dendrobium, Metropolitan, Russell Vale and Wongawilli mines, including recommending measures to improve the way mining effects, impacts and consequences in relation to water quantity are assessed and managed.
    b. In developing its advice, the Panel will meet, undertake site visits, seek information and data, and consult as needed.
    c. Establish a process for and invite public submissions, including from public authorities and special interest groups.
    d. In delivering its report, the Panel will provide comment on and make observations or recommendations about any information or factors the Panel believes relevant, including requirements to strengthen monitoring networks or undertaking further scientific research.
    e. The report is to be delivered no later than 31 December 2018.

NOTE: the reporting date has subsequently been extended to 14 October 2019

3. **Provide advice as required to the Department of Planning and Environment on mining activities in the Greater Sydney Water Catchment Special Areas, which may include but is not confined to:**
    a. A Subsidence Management Plan application for Longwall 16 at the Dendrobium mine.
    b. An Extraction Plan application for Longwall 303 at the Metropolitan mine.
    c. An Environmental Impact Statement for the Dendrobium Extension Project.
    d. A Preferred Project Report for the Russell Vale Underground Expansion Project.
    e. A modification application for the Wongawilli mine.

The Panel

The Independent Expert Panel is comprised of a Chair and technical experts with expertise in mining, mining subsidence, surface water, ground water and swamps.

- Emeritus Professor Jim Galvin (Chair)
- Professor Neil McIntyre
- Dr Ann Young
- Mr Michael Williams
- Dr Christopher Armstrong
- Professor Ismet Canbulat (from January 2019)
- Professor Bruce Hebblewhite (to 8 April 2018)

The Panel draws on other sources of specialist expertise as needed at the discretion of the Chair.

Secretariat support for the Independent Expert Panel is provided by the Office of the Chief Scientist & Engineer.

APPENDIX 2: SITE VISITS, BRIEFINGS AND SUBMISSIONS

Table A2.1: Site Visits

Date	Location	Present
20/02/2018	• Sandy Creek Tributary SC10C • Water Course WC21 • Swamp Den01b • Swamp Den14	**Panel members:** Jim Galvin Ann Young Neil McIntyre Michael Williams (morning only) Christopher Armstrong **WaterNSW:** Fiona Smith, Executive Manager Water and Catchment Protection (morning only) Malcolm Hughes, Manager Catchment Protection Peter Dupen, Manager Mining (morning only) Kel Lambkin, Senior Catchment Officer (morning only) Amanda Ryan, Catchment Field Officer (morning only) **South32 Illawarra Coal:** (afternoon only, Den14 and Den01b site visit) Gary Brassington, Principal Approvals Kai Whitaker, Illawarra Coal Field Team **Secretariat:** Suzanne Pierce Jaclyn Aldenhoven
26/03/2018	Waratah Rivulet, specifically • Flat Rock Swamp • Pool A and rockbar WRS3 • Pool F and rockbar WRS4 • Flat Rock Crossing at Fire Road 9H • Eastern Tributary Crossing at Fire Road 9J	**Panel members:** Jim Galvin Ann Young Neil McIntyre Bruce Hebblewhite* Christopher Armstrong **WaterNSW:** Peter Dupen, Mining Manager **Peabody, Metropolitan Coal:** Jon Degotardi, Technical Services Manager Stephen Love, Environment & Community Superintendent Andy Hyslop, General Manager Peter Baker, SVP Underground Operations Micheal Alexander, Director Projects & Portfolio Management NSW Suzanne Cryle, Manager Community Relations **Resource Strategies:** Stacey Gromadzki, Senior Environmental Manager **Secretariat:** Suzanne Pierce Jaclyn Aldenhoven
31/08/2018	• Reservoir below full supply level of Eastern Tributary • All pools from ETO to ETAU (upstream to Eastern Tributary) • Pool ETF • Swamp 50 • Catchment K Gauge Station	**Panel members:** Jim Galvin Ann Young Neil McIntyre **WaterNSW:** Malcolm Hughes, Manager Catchment Protection **Peabody, Metropolitan Coal:** Jon Degotardi, Manager Technical Services Stephen Love, Environment & Community Superintendent Andy Hyslop, General Manager Kane Organ, Environment & Community Coordinator

		Secretariat: Ella Rasmussen
27/02/2019	• Watercourse LA2 to look at LA2S1 flow site • Lower part of NDT1 • Native Dog Creek • Waterfall WF_54 on Wongawilli Creek	**Panel members:** Jim Galvin Ann Young Neil McIntyre Michael Williams Ismet Canbulat Christopher Armstrong **WaterNSW:** Malcolm Hughes, Manager Catchment Protection **Office of Environment and Heritage:** Martin Krogh, Principal Scientist Major Assessments **South32 Illawarra Coal:** Gary Brassington, Superintendent Approvals Rachel Cameron, Manager Corporate Affairs Bob Skuza, Manager Support Services Josh Carlon, Environmental Coordinator Richard Walsh, Superintendent Exploration **HGEO:** Stuart Brown, Director **Secretariat:** Jerein Kailath

*Note: Professor Bruce Hebblewhite was a Panel member until 8 April 2018.

Table A2.2: Briefings

Date	Location	Present
5/03/2018	Pardalote Meeting Room Level 48, MLC Centre 19 Martin Place, Sydney	**Panel members:** Jim Galvin Ann Young Neil McIntyre Michael Williams Bruce Hebblewhite* Christopher Armstrong **Peabody, Metropolitan Coal:** Jon Degotardi, Technical Services Manager Stephen Love, Environment & Community Superintendent Micheal Alexander, Director Projects and Portfolio Management (NSW) **Resource Strategies:** Stacey Gromadzki, Senior Environmental Manager **Secretariat:** Suzanne Pierce Jaclyn Aldenhoven Jerein Kailath
5/03/2018	Pardalote Meeting Room Level 48, MLC Centre 19 Martin Place, Sydney	**Panel members:** Jim Galvin Ann Young Neil McIntyre Michael Williams Bruce Hebblewhite* Christopher Armstrong **South32 Illawarra Coal:** Gary Brassington, Principal Approvals Rachel Cameron, Manager External Affairs Bryony Andrew, Dendrobium Mine Operations Manager

		HGEO: Stuart Brown, Director **HydroSimulations:** Will Minchin, Senior Hydrogeologist **MSEC:** James Barbato, Engineering Associate **Secretariat:** Suzanne Pierce Jaclyn Aldenhoven Jerein Kailath
26/03/2018	Conference Room Metropolitan Coal Parkes Street, Helensburgh	**Panel members:** Jim Galvin Ann Young Neil McIntyre Michael Williams (teleconference) Bruce Hebblewhite* Christopher Armstrong **WaterNSW:** Fiona Smith, Executive Manager Water and Catchment Protection Malcolm Hughes, Manager Catchment Protection Peter Dupen, Manager Mining **Secretariat:** Suzanne Pierce Jaclyn Aldenhoven Jerein Kailath (teleconference)
3/04/2018	Pardalote Meeting Room Level 48, MLC Centre 19 Martin Place, Sydney	**Panel members:** Jim Galvin Ann Young Neil McIntyre Michael Williams Christopher Armstrong **South32 Illawarra Coal:** Jason Economidis, Vice President Operations Gary Brassington, Principal Approvals Rachel Cameron, Manager External Affairs **Secretariat:** Suzanne Pierce Jaclyn Aldenhoven Jerein Kailath

*Note: Professor Bruce Hebblewhite was a Panel member until 8 April 2018.

Table A2.3: Consultations

Date	Location	Present
31/01/2019	Secretary's Boardroom Level 49, MLC Centre 19 Martin Place, Sydney	**Peabody, Metropolitan Coal:** Andy Hyslop, General Manager Jon Degotardi, Technical Services Manager Stephen Love, Environment & Community Superintendent Micheal Alexander, Director Projects and Portfolio Management (NSW) Zoe Scott, Director Government Relations **Resource Strategies:** Stacey Gromadzki, Senior Environmental Manager
		Department of Planning and Environment: Howard Reed, Director Resource Assessments Clay Preshaw, Director Resource and Energy Assessments

		Lithgow Environment Group: Richard Stiles **Georges River Environmental Alliance:** Sharyn Cullis **National Parks Association, Southern Sydney:** Gary Schoer **Illawarra Residents for Responsible Mining:** Cherrida Hardaker Kaye Osborn **Lock the Gate Inc.:** Nic Clyde **The Colong Foundation for Wilderness Ltd.:** Keith Muir
		Wollongong Coal: Warwick Lidbury, Mining Manager – Russell Vale Colliery **SMEC:** Eladio Perez, Associate Scientist
		National Resource Access Regulator (NRAR): Gregory Abood, Director Compliance Operations East Timothy Gilbert, Director Capability and Coordination
		Office of Environment and Heritage (OEH): Martin Krogh, Principal Scientist Major Assessments
12/02/2019	Auditorium, Picton Bowling Club 10 Cliffe Street, Picton	**South32:** Gary Brassington, Superintendent Approvals Bob Skuza, Manager Support Services Rachel Cameron, Manager Corporate Affairs Jason Economidis, Vice President Operations
		WaterNSW: Peter Dupen, Manager Mining Malcolm Hughes, Manager Catchment Protection Fiona Smith, Executive Manager Water and Catchment Protection
		Chris Owens **Battle for Berrima:** Christopher Mallet Rod Blay **Berrima Resident's Association:** Clive West **Illawarra Residents for Responsible Mining:** Gavin Workman Deidre Stewart **Knitting Nannas:** Caroline Graham **National Parks Association, Macarthur:** Julie Sheppard **Wilton Action Group:** Fiona Bullivant Brian Williams
		Illawarra Local Aboriginal Land Council: Paul Knight, CEO **Wollondilly Council:**

		Noel Lowry, Councillor David Henry, Environment Assessment Planner Bruce Devonport, Team Leader Environmental Services Alexandra Stengl, Manager Environmental Outcomes **Wollongong City Council:** Ron Zwicker, Special Projects and Planning Support Manager
28/02/2019	Meeting Room, Russell Vale Colliery, 7 Princes Highway, Corrimal	**Wollongong Coal:** Mitch Jakeman, Chief Executive Officer Wayne Sly, Chief Operating Officer Warwick Lidbury, Mining Manager – Russell Vale Colliery **SMEC:** Eladio Perez, Associate Scientist **Jindal Steel and Power:** Devendra Vyas, Associate Vice President
	Monte Carlo Room, The Fraternity Club, 11 Bourke St, Fairy Meadow	**Community Consultative Committees** **Dendrobium CCC:** Jenny Evans Phil Diamond **Metropolitan CCC:** Allan House Lisa Andrews Bob Scullion **Russell Vale CCC:** Gavin Workman **Wongawilli CCC:** Ron Cooper Ann Brown Amanda Morris
		Office of Environment and Heritage (OEH): James Dawson, Senior Team Leader, Ecosystems and Threatened Species Martin Krogh, Principal Scientist Major Assessments
		Dam Safety Committee (DSC): Norm Himsley, DSC Member Bill Zeigler, Manager Mining Projects
		Illawarra Knitting Nannas Against Greed: Ann Gadd Shirley Gladding Annie Marlow

Table A2.4: Submissions

No.	Organisation
1	National Parks Association of NSW
2	WaterNSW
3	Wollondilly Shire Council
4	National Parks Association of NSW
5	Lock the Gate Alliance
6	Wilton Action Group
7	National Parks Association, Southern Sydney
8	Battle for Berrima
9	Colong Foundation for Wilderness
10	Colong Foundation for Wilderness 2

11	National Parks Association, Southern Sydney 2
12	CONFIDENTIAL
13	CFMEU Mining and Energy Division
14	BlueScope Steel
15	Ryde Hunters Hill Flora and Fauna Preservation Society
16	Dam Safety Committee
17	Colong Foundation for Wilderness 3
18	Georges River Environmental Alliance
19	Lane Cove Coal and Gas Watch
20	Office of Environment and Heritage
21	National Parks Association, Illawarra
22	National Parks Association, Macarthur
23	Illawarra Residents for Responsible Mining
24	Wollondilly Shire Council 2
25	Wollongong City Council
26	Peabody
27	NSW Minerals Council
28	Environment Protection Authority
29	South32
30	WaterNSW 2
31	Kylie Flament
32	Anne Marett
33	Stephen Young
34	Adrian Ingleby
35	CONFIDENTIAL
36	Martin Cocker
37	Deidre Stuart
38	CONFIDENTIAL
39	Philip Laird
40	CONFIDENTIAL
41	Peggy Fisher
42	Danya Luo
43	Gavin Workman
44	John Croker
45	CONFIDENTIAL
46	Department of Industry – Water
47	Jill Green
48	Christine Bilsland
49	Martin Rowney
50	Mignon Steele
51	Winnie Fu
52	Desmond Jacobs
53	Deborah Truneckova
54	Susan Benham
55	Paul Myjavec
56	Julie Marlow
57	Annie Marlow
58	CONFIDENTIAL
59	Hawkesbury Environment Network
60	Stephen Spencer
61	CONFIDENTIAL
62	CONFIDENTIAL
63	CONFIDENTIAL
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74	CONFIDENTIAL
75	CONFIDENTIAL
76	CONFIDENTIAL
77	CONFIDENTIAL
78	CONFIDENTIAL
79	CONFIDENTIAL
80	CONFIDENTIAL
81	CONFIDENTIAL

Note: Submissions 61 to 81 were marked 'confidential' as stakeholders did not indicate if their submission was public including after follow-up by the Secretariat.